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The Northeast Regional Environmental Impact Study:

Theory, Validation and Application of a Freight Network Equilibrium Model

November 1981

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The Northeast Regional Environmental Impact Study:

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The work reported in this document was initiated under the management of Tobey L. Winters and carried out under the management of Albin J. Zielen, Division of Environmental Impact Studies.

ACRONYMS AND ABBREVIATIONS

ANL	Argonne National Laboratory
DRI	Data Resources, Inc.
DWT	Deadweight (long) tons
FERC	Federal Energy Regulatory Commission
FIPS	Federal Information Processing Standard
FNEM	Freight Network Equilibrium Model
FRA	Federal Railroad Administration
FUA	Powerplant and Industrial Fuel Use Act of 1978
ICC	Interstate Commerce Commission
LIC	Link Identification Code
MNM	Multimodal Network Mode
mph	miles per hour
NEPA	National Environmental Policy Act
NEREIS	Northeast Regional Environmental Impact Statement
NNDB	National Network Data Base
NSPS	New Source Performance Standards
O-D	Origin-Destination
SIP	State Implementation Plan
TERA	Transportation and Economic Research Associates, Inc.
TSC	Transportation Systems Center (USDOT)
USBOM	U.S. Bureau of Mines
USDOE	U.S. Department of Energy
USDOT	U.S. Department of Transportation

ABSTRACT

The U.S. Department of Energy (USDOE) is assessing the potential for cumulative and interactive environmental impacts associated with the proposed conversion to coal of up to 42 powerplants in the Northeast Region of the United States under the Powerplant and Industrial Fuel Use Act of 1978 (Pub. L. 95-620). USDOE's Northeast Regional Environmental Impact Study provides analysis in four interrelated areas: (1) air quality, (2) solid waste disposal, (3) fuel supply and the transportation of fuel and solid waste, and (4) health effects. This document is a description of the main analytical tool developed for analyzing the cumulative impacts of increased coal transportation resulting from the proposed Northeast Regional powerplant conversions. That tool, the Freight Network Equilibrium Model (FNEM), is the first network model that explicitly represents the behavior of both sets of primary transportation decision-makers--the carriers and the shippers. The shippers are modeled as a set of competing interests, each independently seeking to minimize the delivered prices of needed commodities. This is accomplished through the use of a "user-optimized" network equilibrium model. The origin-destination information produced in this phase is then input to a set of "systems-optimized" equilibrium models in which each carrier is assumed to minimize its total operating cost. Included are discussions of the theory and methodology of the model, the data bases required, the logic of the software, and the validation of the model. Results from the application of the model in the Northeast Regional Environmental Impact Study are presented.

1. INTRODUCTION, OBJECTIVE AND COVERAGE OF THE REPORT

1.1 INTRODUCTION

The proposed action to be assessed in the Northeast Regional Environmental Impact Study is the cessation of the use of oil and natural gas as primary energy sources in up to forty-two powerplants in the northeastern United States. The objective of the proposed action is, in consonance with the purposes of the Powerplant and Industrial Fuel Use Act of 1978 (FUA) (Pub. L. 95-620), to minimize or eliminate oil consumption in as many of these units as possible. Among the functions that the U.S. Department of Energy (USDOE) performs under the Act are negotiating voluntary conversions and working with those utilities subject to the authorities of the Act to encourage them to pursue conversions.

USDOE can encourage fuel switching away from oil by providing technical analyses of the effects of fuels conversion. The Northeast Regional Environmental Impact Study provides this type of analysis in four interrelated areas: (1) air quality; (2) solid waste disposal; (3) fuel supply and the transportation of fuel and solid waste; and (4) health effects. A separate technical task report is being prepared in each of these areas, and will serve both as a general reference document and as a technical reference for the Northeast Regional Environmental Impact Statement (NEREIS) (USDOE 1981; DOE/EIS-0083-D) and for the site-specific environmental impact statements issued under the Fuel Use Act.

The primary purpose of the Northeast Regional Environmental Impact Study is to assess and document the potential for cumulative and interactive environmental impacts associated with the conversion of multiple generating stations in the Northeast. The 42 facilities included in the study (see Table 1.1) were selected because they were considered by the President's Coal Commission to be coal-capable. This Commission originally compiled a list of 117 generating stations that were considered capable of using coal. This list was reduced by USDOE using the criteria of eliminating: (1) all units over twenty-five years of age; and (2) stations with an aggregate capacity of less than 100 megawatts. The size and age criteria focused attention on powerplants that had the greatest potential for oil displacement and economic benefits, and on units having the longest remaining useful life. The overall area addressed by the Northeast Regional Environmental Impact Study is the macroregion defined by Maryland to the south and Maine to the north. The facilities are distributed over 10 states* in the Northeast, with a majority of them clustered in the New York-New Jersey-Connecticut tri-state region (Fig. 1.1). In addition, in the area of air quality, specific attention is focused on four subregions centering around Boston, New York City, Philadelphia, and Baltimore. The depth and breadth of coverage of this regional analysis is sufficient to provide a data base and analysis for site-specific environmental analysis as well as a broader perspective of the overall impacts on the Northeast Region, as described in the NEREIS. Detailed treatment is not included in the study, nor are aspects more relevant to site-specific environmental impact statements. Instead, generic issues that are cumulative or interactive on a regional basis are emphasized. This approach conforms to the intent of the National Environmental Policy Act (NEPA) in general, and to the Council on Environmental Quality Regulations on implementing NEPA procedures in particular, as the technical reports provide data used in the analysis done for the NEREIS, the middle tier of a three-tiered approach to impact assessment. The first tier is the published Final Programmatic Environmental Impact Statement for the Fuel Use Act (USDOE 1979a) and the Revised Programmatic Environmental Impact Statement for the Energy Supply and Environmental Coordination Act (Federal Energy Administration 1977). The final tier is composed of the site-specific environmental impact statements.

1.2 OBJECTIVE AND COVERAGE

This document is the technical task report on fuel supply and the transportation of fuel and solid waste. It presents a description of a state-of-the-art freight network model and the supporting data bases developed to provide USDOE with a computer-based methodology for analyzing impacts on the transportation system (rail and barge) of increased coal movement into and within the northeastern United States resulting from FUA coal conversions. This model was developed as part of the Northeast Regional Environmental Impact Study, in support of the Northeast Regional Environmental Impact Statement (NEREIS).

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*Vermont generally has been excluded from the study, as the state contains none of the subject utility boilers, nor is it considered a location for combustion waste disposal.

Table 1.1. Facilities Included in the Northeast Regional Environmental Impact Study

State/Facility	Unit Number
Connecticut	
Bridgeport Harbor	3
Devon	7,8
Middletown	1,2,3
Montville	5
Norwalk Harbor	1,2
Delaware	
Edge Moor	1,2,3,4
Maine	
Mason	1,2,3,4,5
Maryland	
Brandon Shores	1,2
Crane	1,2
Riverside	4,5
Herbert A. Wagner	1,2
Massachusetts	
Canal	1
Mt. Tom	1
Mystic	4,5,6
New Boston	1,2
Salem Harbor	1,2,3
Somerset	6
West Springfield	3
New Hampshire	
Schiller	4,5,6
New Jersey	
Bergen	1,2
Burlington	7
Deepwater	7,8,9
Hudson	1
Kearny	7,8
Sayreville	4,5
Sewaren	1,2,3,4
New York	
Albany	1,2,3,4
Arthur Kill	2,3
Danskammer Point	1,2,3,4
E.F. Barrett	1,2
Far Rockaway	4
Glenwood	4,5
Lovett	3,4,5
Northport	1,2,3,4
Oswego	1,2,3,4
Port Jefferson	1,2,3,4
Ravenswood	3
Pennsylvania	
Cromby	2
Schuylkill	1
Southwark	1,2
Springdale	7,8
Rhode Island	
South Street	12

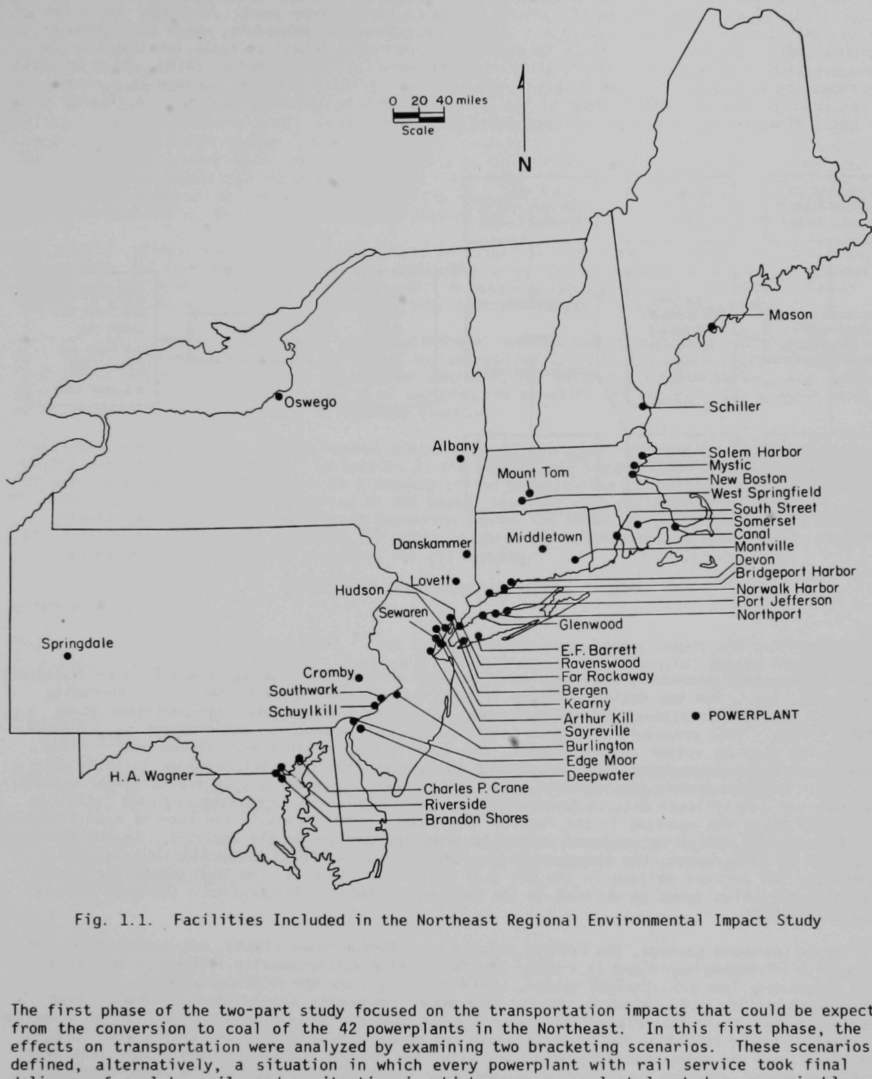

Fig. 1.1. Facilities Included in the Northeast Regional Environmental Impact Study

The first phase of the two-part study focused on the transportation impacts that could be expected from the conversion to coal of the 42 powerplants in the Northeast. In this first phase, the effects on transportation were analyzed by examining two bracketing scenarios. These scenarios defined, alternatively, a situation in which every powerplant with rail service took final delivery of coal by rail, and a situation in which every powerplant located on a navigable waterway took delivery of coal by ship or barge. These scenarios indicate where bottlenecks and congestion are likely to occur. The results of this analysis are contained in the NEREIS.

The second phase of the study, which is the basis of this technical report, is a much more detailed transportation network analysis of the effects on railroad and port congestion due to increases in traffic attributable to FUA conversions, in conjunction with other increases in traffic, as well as a detailed assessment of rail and water modal shares. This report presents a discussion of the network model, data bases, and software logic developed for this detailed analysis.

The basis of the analysis is the national supply and demand forecasts for coal generated by the Data Resources, Inc. (DRI) Coal Model*. A general description of this model is presented in Appendix A. However, it should be understood that the network model developed for this analysis itself is in no way committed to DRI; other models could have been used. The major tools for the analysis are two software packages: (1) the disaggregation procedure, which disaggregates regional supply and demand forecasts to a level of geographic detail suitable for input to the transportation network model, and (2) the Freight Network Equilibrium Model (FNEM), which predicts the commodity movements on the transportation network. A third software package is a report writer used to generate descriptions of the solutions found by the network model. A diagram of the basic elements of the analysis is presented in Figure 1.2.

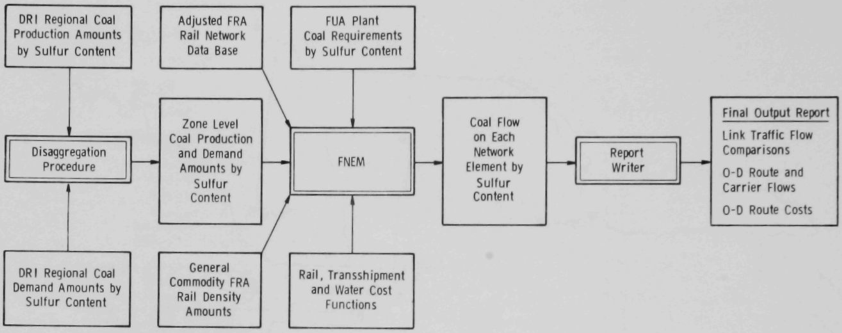

Fig. 1.2. Impact Assessment Methodology

The disaggregation procedure, an extension of earlier work by Transportation and Economic Research Associates, Inc., for the National Energy Transportation Study, permits the use of commodity forecasts made on a national or regional level in a more disaggregate transportation study (USDOE 1979b). This procedure uses data on historical coal production and consumption, reserves, descriptive data on sulfur and Btu levels, the locations of present and planned coal-burning powerplants, and geographical data describing the various regional delineations in terms of counties. Since many data are reported on a county level, by relating counties to larger regions and reported county-level data to forecasted regional values, any forecasted regional total can be divided among the counties in the region. The county-level forecasts can then be used directly or combined into some other regional definition more appropriate to the analysis. In the application described in this report, the disaggregation procedure divides total production and consumption forecasted for regions defined in the DRI Coal Model into counties, and then reconstructs them into transportation zones as defined in the Federal Railroad Administration's National Network Data Base (NNDB).

The second software package, the Freight Network Equilibrium Model (FNEM), was developed by the University of Pennsylvania and is a model for forecasting multicommodity intermodal transportation flows over the U.S. freight system. FNEM directly uses the NNDB and augments it with a description of the U.S. waterway system. The model represents a considerable advance over previous models as it explicitly treats both freight shippers and freight carriers in the presence of elastic demand functions for transportation and congestion externalities articulated through nonlinear cost and delay functions that vary with flow volumes. Previous models have tended to emphasize <u>either</u> shippers <u>or</u> carriers, essentially ignoring the effect of the other component

*Eight coal models were investigated for the purpose of developing coal supply and demand forecast scenarios. Of these, six models--the Energy and Environmental Analysis (EEA) coal model, the National Coal Model (NCM), the Charles River Associates/Electrical Power Research Institute (CRA/EPRI) coal model, the Data Resource, Inc. (DRI) coal model, the PACE model, and the Midterm Energy Forecasting System (MEFS)--were studied in more detail regarding their theoretical underpinnings, model specifications, availability, user's flexibility and interface, and cost. The DRI coal model appeared to be the best in all these respects.

of the decision-making process. FNEM was applied to the Northeast freight system in such a way that the shippers (buyers and sellers of coal) determine how much coal will move from place to place, and in general terms how the shipment is to be made (which overall rail/water route). The carriers, specifically the railroad companies, determine in detail which route to use within their respective company systems. The shippers' model is driven by the availability of supplies, demand for coal, and transportation rates. The carriers' model is supplied origin-destination tonnage demands and solves for efficient use of the system given the link-by-link costs of operation, which are subject to link-by-link traffic levels. The output of the model is a detailed computation of link-by-link traffic levels. These are translated to the Federal Railroad Administration's (FRA) original codes and tonnages for the different scenarios are compared in the report writer. Further outputs include a listing of origin-destination pairs and shipper and carrier model routes and costs. In the present version of the FNEM, these were interpreted and summarized outside the model. All FNEM calculations pertaining to coal are coupled with analyses of noncoal commodities to ensure accuracy with respect to estimates of increased congestion, bottlenecks, and displacement and delay of noncoal commodities.

The analysis effort also reflects a comprehensive effort to update the FRA NNDB. In particular, the network was examined for missing arcs and nodes to ensure its connectivity, and was updated to reflect the most recent rail abandonments. A detailed description of the nation's intercoastal and inland waterway system also was developed and coupled to the updated NNDB.

Although the transportation impacts of increased coal haulage in the Northeast are emphasized in this report, the model is fully general and may be applied to virtually any freight transportation/impact analysis task, either regional or national, for which the supporting data are available. The special features and results of applying the model to the entire U.S., as well as to other regions, will be addressed in separate reports.

The theoretical basis and methodological discussions of both the FNEM and the disaggregation methods are given in Section 2. In Section 3, the sources and organization of the data used in the model are outlined. Section 4 is a summary of the organization of the software, and Section 5 is a description of a test problem run on the model, together with validation exercises. Finally, the outputs and analysis of one of the scenarios run on the model are presented in Section 6. The scenario is the Oil SIP Scenario for 1991, in which converted plants are subject to State Implementation Plan air quality standards for oil burning.

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2. THEORY AND METHODOLOGY

2.1 THEORETICAL BASIS OF THE FREIGHT NETWORK EQUILIBRIUM MODEL

In the traditional user-optimized network equilibrium problem (Wardrop 1952), the problem is to find the traffic pattern, such that for each origin-destination (O-D) pair, no user acting unilaterally can find a shorter path than the one already being used. This is equivalent to saying that

$$
\begin{aligned}
& C_{p_1}(h_1) = C_{p_2}(h_2) = \ldots = C_{p_\ell}(h_\ell) \\
& \quad \leqq C_{p_{\ell+1}}(h_{\ell+1}) \leqq C_{p_{\ell+2}}(h_{\ell+2}) \leqq \ldots \leqq C_{p_n}(h_n)
\end{aligned} \tag{1}
$$

if $h_1, h_2 \ldots h_\ell > 0$ and $h_{\ell+1}, h_{\ell+2} \ldots h_n = 0$ are true,

where $C_p(h)$ = the function expressing average travel cost on path p for flow h and

h_i = the flow on path i.

Since this pattern results from the independent actions of many users, each trying to minimize travel costs, it has been widely adopted for analyses of urban passenger highway networks where this type of behavior is assumed to occur.

In transport systems controlled by a single authority, such as the rail network of a single railroad, and where the O-D demands are already known, a common modeling approach has been to assume that the controlling authority (the carrier) is attempting to minimize overall costs. In this case a system-optimized equilibrium problem is encountered (Wardrop 1952). The solution to a systems-optimized problem is a set of flows that for each O-D pair satisfies

$$
\begin{aligned}
& C'_{p_1}(h_1) = C'_{p_2}(h_2) = \ldots = C'_{p_\ell}(h_\ell) \\
& \quad \leqq C'_{p_{\ell+1}}(h_{\ell+1}) < C'_{p_{\ell+2}}(h_{\ell+2}) \leqq \ldots \leqq C'_{p_n}(h_n)
\end{aligned} \tag{2}
$$

if $h_1, h_2, \ldots h_\ell > 0$ and $h_{\ell+1}, h_{\ell+2}, \ldots h_n = 0$ are true,

where $C'_p(h)$ = the function expressing marginal travel cost on path p for flow h and

h_i = the flow of path i.

Since for each O-D pair the marginal cost of any path used does not exceed the marginal cost of any other path (used or unused), total system cost cannot decrease through the transfer of flow between paths. This clearly implies the state of minimum total cost.

When dealing with more general freight networks in which the user (shipper) O-D demands have not already been determined, the question arises as to which approach, user- or system-optimized, is more appropriate. Clearly, the behavior of the many individuals and firms that make up the group of shippers is analogous to that of the highway users. They are all acting independently to achieve the cheapest cost transportation route (which includes mode) possible. An equilibrium will exist when no shipper acting independently can improve its travel cost. On the other hand, the carriers are faced with the problem of how to satisfy the shippers' decisions, and each will do so in a cost-minimizing manner.

Typically, the approach that has been used to model these freight networks has been to ignore the behavior of the carriers and adapt one of the urban highway user-optimized models to the needs of the shippers (e.g., Bronzini 1980). This approach is a substantial simplification of the freight system decision-making hierarchy. It is no more realistic than would be the use of a system-optimized model that captures the carriers' behavior but ignores the actions of the shippers (Friesz and Morlok 1980). The Freight Network Equilibrium Model (FNEM) developed for use in this study (Friesz et al. 1981) is designed to be a computationally tractable model that explicitly accounts for the interaction between shippers and carriers rather than the behavior of just one of these groups. Since the model was developed as a means of analyzing the transportation impacts of increased coal usage, it has the consignees (the users of coal, primarily electric utilities) making decisions about where to purchase and how to ship the freight. These utilities are the shippers in this model. It would be easy, however, to reformulate the model to account for consignor, rather than consignee, decision-making. Many of the key ideas on which the model is based have their genesis in the work of Friesz and Fernandez (1979), assessing the feasibility of advanced freight/passenger network models in developing countries.

2.1.1 Model Description

To represent the behavior of shippers and carriers accurately, the FNEM is divided into two submodels that are applied sequentially. The shippers' submodel is a simultaneous distribution, modal split, and traffic assignment model. It is applied first to predict a user-optimized equilibrium flow and modal split. This defines a set of origin-destination demands and a general routing pattern, which are then used as inputs to the carriers' submodel. The carrier's submodel is then applied to determine a system-optimized equilibrium flow for each carrier. An overview of this process is illustrated in Figure 2.1. Descriptions of each submodel are presented in the following sections.

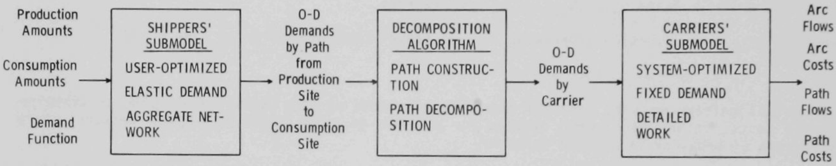


Fig. 2.1. Overview of Freight Network Equilibrium Model

2.1.2 Shippers' Submodel

2.1.2.1 Description

The shippers' submodel routes traffic over an abstract aggregate representation of the freight transportation network. This aggregate network includes only the modes that might realistically be considered by shippers. In the discussion that follows, the term "mode" also includes combinations of modes. For example, in the network shown in Figure 2.2, the possible modes from O to D are rail, water, and water/rail. Although the aggregate network varies from application to application, its nodes include all potential origins, destinations, transshipment sites, and inter-carrier transfer points (gateways). In addition, locations such as major points of transportation activity that might be of special interest can be added. An example of this aggregation for the shipment of coal is given in Figure 2.3. This aggregate network is used instead of the real network because it is this representation of the transportation system that the shippers actually "see" when making routing choices. Shippers are concerned with, and have the power to determine, the O-D pairs; mode(s) used; the location of transshipments (if any); and, to some extent, a general routing pattern. Unless private carriage is used, they neither have information about, nor control over, the detailed routing choices with which the carriers are faced.

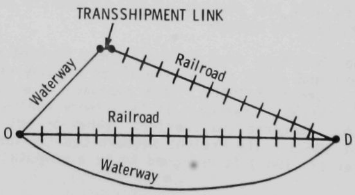


Fig. 2.2. Network Showing Possible O-D Modes

To facilitate discussion of how the shippers will distribute their traffic over this aggregate network, the following notation is employed:

e = an element of the network (either an arc or a node),

E = set of all elements of the network,

r = commodity,

s = mode,

t_e^{rs} = travel time using element e for commodity r transported by mode s,

c_e^{rs} = cost of the carrier of using element e to transport commodity r by mode s,

f_e^{rs} = flow of commodity r transported by mode s over element e,

f_e = vector of commodity/mode flows for element e = $(\ldots,f_e^{rs},\ldots)$,

f = vector of element flows $(\ldots,f_e,\ldots)$,

i = origin,

j = destination,

w = origin-destination pair (i, j),

W_i = set of w with origin i,

W_j = set of w with destination j,

p = path,

P_w^{rs} = set of paths between O-D pair w with commodity r carried by mode s,

h_p^{rs} = flow of commodity r by mode s over path p,

h_p = vector of commodity/mode flow for path p $(\ldots,h_p^{rs},\ldots)$,

h = vector of path flows $(\ldots,h_p,\ldots)$,

δ_{ep} = 1 if element e is on path p, 0 otherwise,

O_i^r = amount of commodity r produced at origin i,

D_j^r = amount of commodity r demanded at destination j,

m_i^r = purchase price of commodity r when purchased at origin i,

z_w^{rs} = base transportation rate for commodity r by mode s between O-D pair w,

T_w^{rs} = demand for commodity r by mode s between O-D pair w,

T_w = vector of commodity/mode demands $(\ldots,T_w^{rs},\ldots)$,

T = vector of O-D demands $(\ldots,T_w,\ldots)$,

M_w^{rs} = the fraction of commodity r transported by mode s between O-D pair w,

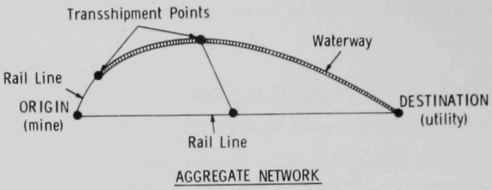
t_p^{rs} = travel time for commodity r by mode s over path p,

c_p^{rs} = cost to the carrier of transporting commodity r by mode s over path p,

q_r = value of time (\$/hr/unit shipped) for commodity r,

ε_s = permeability factor for mode s (the fraction of the carriers' operating cost that is passed onto the shipper), and

DP_{wp}^{rs} = delivered price of commodity r by mode s by path p between O-D pair w.



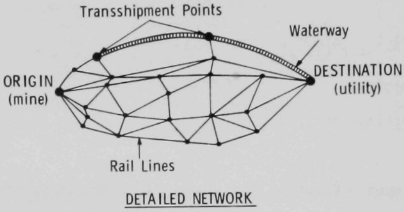


Fig. 2.3. Network Aggregation

This notation makes it possible to describe the assumptions made about shipper behavior and the basic relationships that must exist for any optimal pattern of flows.

It is assumed that the extent of production and consumption activity already is known, i.e., the O_i^r's and D_j^r's are fixed. It is further assumed that each shipper is separately and noncooperatively seeking to minimize the final delivered price of the commodity it is purchasing. The final delivered price to the shipper is determined by the combination of commodity, origin, mode, and path selected, and can be expressed as

$$DP_{wp}^{rs} = q_r t_p^{rs} + m_i^r + z_w^{rs} + \varepsilon c_p^{rs} \ . \tag{3}$$

It should be noted that the actual money expended on transportation is expressed by the third and fourth terms only. It is assumed here that this amount is equal to some base rate plus a specified percentage of the actual cost of shipment. The z_w^{rs} can be considered to be the posted tariff between O-D pair w for commodity r by mode s. The ε can then be adjusted to represent the degree of freedom that the carrier is permitted to vary from this tariff given the costs it is incurring in making these shipments. If an unregulated market situation exists, the ε term can be reinterpreted as a profit multiplier, and the z_w^{rs} term can then be deleted. If the market is highly regulated, then the ε is set equal to zero and the z_w^{rs} term retained. Generalized cost measures for freight systems such as Equation 3 have been proposed by Tourreilles (1979).

In a user-optimized solution on the shippers' network it is expected that for each commodity and demand site the delivered prices will play the role of the abstract cost functions given in Equation 1, i.e.,

$$DP_{wp_1}^{rs} = DP_{wp_2}^{rs} = \ldots = DP_{wp_\ell}^{rs} < DP_{wp_{\ell+1}}^{rs} < DP_{wp_{\ell+2}}^{rs} < \ldots < DP_{wp_n}^{rs} \tag{4}$$

if $h_1, h_2, \ldots, h_\ell > 0$ and $h_{\ell+1}, h_{\ell+2}, \ldots, h_n = 0$.

The O-D demand functions must generally be specified for each application of the model. However, the model includes an option for specifying no demand functions, in which case O-D demands are determined directly from Wardrop's first principle. This option is invoked when one wishes to model transportation demand as purely derived from the consumption and production characteristics of spatially separated markets; it is a useful feature when reliable transportation demand functions for the level of commodity disaggregation and modes considered are not available. Modal split is determined directly from Wardrop's first principle in such a way that total commodity production and attraction constraints are satisfied; thus, the model is a distribution, mode split, and assignment model. It is important to realize that the multimodal nature of this problem together with the fact that demand is described through the variables T_w^{rs} results in a well-defined modal split:

$$M_w^{rs} = \frac{T_w^{rs}}{\sum_m T_w^{rm}} . \tag{5}$$

A well-known transportation demand function (Wilson 1970) is the negative exponential function

$$T_w^{rs} = A_i^r \; B_j^r \; O_i^r \; D_j^r \exp\left(-\theta^r \; DP_{wp}^{rs}\right), \tag{6}$$

where A_i^r, B_j^r and θ^r are parameters that must be determined to ensure that Equation 6 correctly describes transportation demand for the particular circumstances being analyzed. It is important to note that the transportation demand function (Eq. 6) is one of several that could be articulated.

Keeping the solution requirement (Eq. 4) and the transportation demand function (Eq. 6) in mind, the following equivalent optimization problem is formulated:

$$\text{Minimize } Z = \sum_e \sum_r \sum_s \oint_0^{f_e} \left[q_r \cdot t_e^{rs}(y_e) + \varepsilon_s c_e^{rs}(y_e)\right] dy_e +$$

$$\sum_i \sum_{w \varepsilon W_i} \sum_{p \varepsilon P_w} \sum_r \sum_s m_i^r \, h_p^{rs} + \sum_w \sum_{p \varepsilon P_w} \sum_r \sum_s z_w^{rs} \, h_p^{rs} + \sum_w \sum_r \sum_s \gamma^r \, T_w^{rs} \left(\ell n T_w^{rs} - 1\right) \tag{7}$$

subject to

$$f_e^{rs} = \sum_p \delta_{ep}^{rs} \, h_p^{rs} \tag{8}$$

$$G_w^{rs} = T_w^{rs} - \sum_{p \varepsilon P_w^{rs}} h_p^{rs} = 0 \qquad (u) \tag{9}$$

$$E_i^r = \sum_s \sum_{w \varepsilon W_j} T_w^{rs} - O_i^r = 0 \qquad \forall\, i,r \qquad (\alpha) \tag{10}$$

$$F_j^r = \sum_s \sum_{w \varepsilon W_i} T_w^{rs} - D_j^r = 0 \qquad \forall\, j,r \qquad (\beta) \tag{11}$$

$$T \geqq 0 \qquad (\rho) \tag{12}$$

$$h \geqq 0 . \qquad (\mu) \tag{13}$$

The constraint set specifies the various relationships that must exist for any feasible pattern. The path and arc flows are related in Equation 8 and the path flows and O-D demand are related in Equation 9. The production and consumption constraints are given in Equations 10 and 11, respectively, and the non-negativity constraints are given in Equations 12 and 13. The letters to the right of each set of constraints are appropriately dimensioned vectors of dual variables associated with those constraints. Note that the γ^r are calibration parameters whose meaning is explained below. The symbol $\oint$ in Equation 7 denotes a line integral.

If t_e^{rs} and c_e^{rs} are both monotone increasing, then Z is convex and the Kuhn-Tucker conditions for this program will be both necessary and sufficient. The Kuhn-Tucker conditions are:

$$\nabla_h Z + u \nabla_h G - \mu = 0 \tag{14}$$

$$\nabla_T Z + \alpha \nabla_T E + \beta \nabla_T F + u \nabla_T G - \rho = 0 \tag{15}$$

$$\mu \geqq 0 \tag{16}$$

$$\rho \geqq 0 \tag{17}$$

$$\mu h = 0 \tag{18}$$

$$\rho T = 0 \ . \tag{19}$$

By using the identity

$$\frac{\partial}{\partial h_p^{rs}} = \sum_a \frac{\partial f_e^{rs}}{\partial h_p^{rs}} \frac{\partial}{\partial f_e^{rs}} = \sum_e \delta_{ep}^{rs} \frac{\partial}{\partial f_e^{rs}} \ , \tag{20}$$

it is easy to see that

$$\nabla_h Z = \left(\ldots, \sum_e \left[q_r \cdot \delta_{ep}^{rs} \cdot t_{ep}^{rs} + \varepsilon_s \cdot \delta_{ep}^{rs} \cdot c_e^{rs} \right] + m_i^r + z_w^{rs} \ , \ldots \right) . \tag{21}$$

Note that, by definition,

$$\sum_e \delta_{ep}^{rs} t_e^{rs} = t_p^{rs} \tag{22}$$

$$\sum_e \delta_{ep}^{rs} c_e^{rs} = c_p^{rs} \ . \tag{23}$$

Using Equations 22 and 23, Equation 21 yields

$$\nabla_h Z = \left(\ldots, q_r \ t_p^{rs} + \varepsilon_s \ c_p^{rs} + m_i^r \ Z_w^{rs} \ , \ldots \right) . \tag{24}$$

Substituting Equation 24 into Equation 14 yields

$$q_r \ t_p^{rs} + \varepsilon_s c_p^{rs} + m_i^r + z_w^{rs} - u_w^{rs} - \mu_p^{rs} = 0 \ . \tag{25}$$

Taking advantage of the complementary slackness conditions (Eqs. 16 and 18), Equation 25 can be rewritten as

$$D_{wp}^{rs} = q_r t_p^{rs} + \varepsilon c_p^{rs} + m_i^r + z_w^{rs} \begin{cases} = u_w^{rs} \text{ if } h_p^{rs} > 0 \\ > u_w^{rs} \text{ if } h_p^{rs} = 0 \ . \end{cases} \tag{26}$$

This is exactly the set of conditions set forth in Equation 4 for a user-optimized solution.

Note that

$$\nabla_T Z = \left(\ldots, \gamma^r \ T_w^{rs}, \ldots \right) . \tag{27}$$

Substituting Equation 27 into Equation 15 yields

$$\gamma^r \ \ell n T_w^{rs} + \alpha_i^r + \beta_j^r + u_w^{rs} - \rho_w^{rs} = 0 \ . \tag{28}$$

Because of the complementary slackness conditions (Eqs. 17 and 19), $\rho_w^{rs} = 0$ when $T_w^{rs} > 0$. Under this condition Equation 28 becomes

$$T_w^{rs} = \exp\left(-\alpha_i^r/\gamma^r\right) \exp\left(-\beta_j^r/\gamma^r\right) \cdot \exp\left(-u_w^{rs}/\gamma^r\right). \tag{29}$$

By defining

$$A_i^r \equiv \exp\left(-\alpha_i^r/\gamma^r \; /O_i^r\right) \tag{30}$$

$$B_j^r \equiv \exp\left(-\beta_j^r/\gamma^r \; /D_j^r\right) \tag{31}$$

$$\theta^r = 1/\gamma^r \quad , \tag{32}$$

Equation 29 can be put in the form

$$T_w^{rs} = A_i^r \; B_j^r \; O_i^r \; D_j^r \; \exp\left(-\theta^r \; u_w^{rs}\right) .$$

It is known from Equation 26 that $u_w^{rs} = DP_{wp}^{rs}$ and so the desired negative exponential demand (Eq. 6) is implicit in the equivalent optimization problem. It is also significant that the negative exponential demand (Eq. 6), when substituted into the modal split equation (Eq. 5), yields the well-known logit modal split model:

$$M_w^{rs} = \frac{\exp\left(-\theta^r \; DP_{wp}^{rs}\right)}{\sum_m \exp\left(-\theta^r \; DP_{wp}^{rm}\right)} \quad . \tag{33}$$

The results just derived will hold only if the line integral in the objective function is path-independent. A condition both necessary and sufficient for path independence is that the Jacobian matrix of element costs (consisting of $K_{es}^r = q_r \; t_e^{rs} + \varepsilon_s \; c_e^{rs}$) be symmetric, i.e.,

$$\frac{\partial K_e^{rs}}{\partial f_e^{xy}} = \frac{\partial K_e^{xy}}{\partial f_e^{rs}} \quad . \tag{34}$$

If we refer to each mode-commodity combination as a user class, Equation 34 requires that the change in the cost of any user class on a particular network element experienced as a result of a change in flow of a different user class on that element must be the same as the influence that the second class has on the first. Although this symmetry assumption sounds quite restrictive, there are many types of freight analyses where it applies. For example, if different freight modes never share any network elements (railroads on rail links, trucks on highways, etc.) and if different commodities on the same mode are treated similarly by the carrier, then the symmetry assumption will be valid. Sometimes, however, different commodities are given different priorities by the carriers. In this case the model can be used sequentially--first for the highest-priority goods, then for the next-highest-priority (taking into account the previous link loadings), etc.

Back-hauling may be accommodated in the theoretical structure presented above in a number of ways. The most straightforward approach to doing this is to assume that the empty cars will be returned over the same paths used in the fore-haul, and to adjust the flow levels accordingly. This would be especially appropriate for unit train movements. Another approach is to model general-purpose rail cars as separate commodities, with supplies and demands for these commodities being generated by the demands and supplies of those commodities requiring the rail cars. Also, the model accounts for yard delays through either the representation of yards as links or through the appropriate modification of link cost and delay functions to represent the presence of yards.

2.1.2.2 Solution Algorithm

Since the shippers' submodel might easily include thousands of variables and constraints when being applied to a typical regional freight network, the algorithm used to obtain its solution must be as efficient as possible. In particular, the enumeration of paths that can easily number in the millions must be avoided. Fortunately, the shippers' submodel, although non-linear in the objective function, has only linear constraints. There are solution techniques for mathematical programs of this type which, when properly applied, can eliminate the need for path enumeration. The particular algorithm chosen for solution of the shippers' submodel is the Frank-Wolfe algorithm, frequently used for urban traffic equilibrium problems (see Gartner 1977). The use of this algorithm for the shippers' submodel requires the solution of a shortest path problem and a special type of linear program known as a Hitchcock or transportation problem, together with a one-dimensional line search at each iteration.

Applying the Frank-Wolfe algorithm to the shippers' submodel, therefore, requires solving a sequence of linear programs of the form

$$\text{Minimize } \hat{Z} = \sum_w \sum_p \sum_r \sum_s A_{wp}^{rs} \cdot h_p^{rs} + \sum_w \sum_r \sum_s B_w^{rs} \cdot T_w^{rs} \tag{35}$$

$$\text{s.t.} \quad \left| \begin{array}{l} E(T) \;\;\;\; = 0 \\ F(T) \;\;\;\; = 0 \\ G(T,h) = 0 \\ T \geqq 0 \\ h \geqq 0 \quad , \end{array} \right.$$

$$\text{where } A_{wp}^{rs} = q_r \cdot t_p^{rs}(\hat{h}) + \varepsilon_s\, c_p^{rs}(\hat{h}) + m_i^r\, z_w^{rs} \text{ , a constant,} \tag{36}$$

$$B_w^{rs} = \gamma^r \ln T_w^{rs} \text{ , a constant,} \tag{37}$$

and $(\hat{h},\hat{T})$ is the current approximate solution.

To avoid path enumeration, the value of A_{wp}^{rs}, although a constant, is dependent on the path chosen. If all of the demand for a given commodity between a given O-D pair is assigned to the shortest path, the first term in the objective function becomes

$$\sum_w \sum_r \sum_s A_{w*}^{rs} \cdot T_w^{rs*} \quad , \tag{38}$$

where A_{w*}^{rs} is the value of A_{wp}^{rs} when the shortest path is used. This clearly leads to the minimum value that the objective function can achieve. Therefore, the solution to

$$\text{Minimize } \hat{Z} = \sum_w \sum_r \sum_s A_{w*}^{rs} \cdot T_w^{rs*} + \sum_w \sum_r \sum_s B_w^{rs} \cdot T_w^{rs} \quad , \tag{39}$$

which has no path index, will be the same as that for Equation 35. Since constraint G has been incorporated into the objective function, the problem becomes

$$\text{Minimize } \sum_w \sum_r \sum_s C_{w*}^{rs} \cdot T_w^{rs} \tag{40}$$

$$E_i^r = \sum_{w \varepsilon W_i} T_w^{rs} - O_i^r = 0 \tag{41}$$

$$F_j^r = \sum_{w \varepsilon W_j} T_w^{rs} - D_j^r = 0 \tag{42}$$

$$T_w^{rs} \geqq 0 \quad , \tag{43}$$

$$\text{where } C_{w*}^{rs} = A_{w*}^{rs} + B_w^{rs} \; . \tag{44}$$

Note that Equations 40-44 are a set of Hitchcock problems, one for each commodity r. There are many efficient solution algorithms for solving these problems. The solution of each Hitchcock problem gives values for T_W^{rs*}. These values can then be used in the line search phase of the Frank-Wolfe algorithm. The line search can be carried out by one of a number of efficient techniques, such as Golden Section search or a binary search.

The application of the Frank-Wolfe algorithm to the shippers' submodel can be summarized as follows:

Step 1 Obtain an initial feasible solution $\left(\hat{T}_w^{rs}, \hat{f}_e^{rs}\right)$ to the shipper equilibrium problem.

Step 2 For each O-D pair w and each commodity r determine the shortest path τ_W^{rs} based on element impedances $q_r \cdot t_e^{rs}(\hat{f}) + \varepsilon_S\, c_e^{rs}(f)^W$. (Note that the terms m_i^r and z_W^{rs} do not affect the shortest path determination since these costs will be identical for <u>every</u> path connecting O-D pair w).

Step 3 Determine the impedances C_{w*}^{rs} (which includes $m_i^r + z_w^{rs}$) for all shortest paths τ_w^{rs}.

Step 4 Solve the Hitchcock problems given by Equations 40 through 44 to obtain the new demand values $\bar{T}_w^{rs}$.

Step 5 For all w such that $e \in \tau_w^{rs}$ set $\bar{f}_e^{rs} = \sum_w \bar{T}_w^{rs}$. If $e \notin \tau_w^{rs}$ for all w, then set $\bar{f}_e^{rs} = 0$.

Similarly, set $\bar{h}_p^{rs} = \bar{T}_w^{rs}$ = if $p = \tau_w^{rs}$, and $\bar{h}_p^{rs} = 0$ if $p \neq \tau_w^{rs}$.

Step 6 Compute θ which minimizes $Z(\theta)$, obtained by making the following substitutions in the definition of Z given in Equation 7:

$$h_p^{rs} = \hat{h}_p^{rs} + \theta\left(\bar{h}_p^{rs} - \hat{h}_p^{rs}\right)$$

$$T_w^{rs} = \hat{T}_w^{rs} + \theta\left(\bar{T}_w^{rs} - \hat{T}_w^{rs}\right)$$

$$f_e^{rs} = \hat{f}_e^{rs} + \theta\left(\bar{f}_e^{rs} - \hat{f}_e^{rs}\right) .$$

Step 7 Compute T_w^{rs} and f_e^{rs} using the definitions and value of θ obtained from Step 6.

Step 8 Compute

$$J_1 = \max \left| T_w^{rs} - \hat{T}_w^{rs} \right|$$

$$J_2 = \max \left| f_e^{rs} - \hat{f}_e^{rs} \right| .$$

If $J_1 < \varepsilon$ and $J_2 < \varepsilon$, ε being a preset tolerance, stop; otherwise, define the current solution to be

$$\hat{T}_w^{rs} = T_w^{rs}$$

$$\hat{f}_e^{rs} = f_e^{rs}$$

and go to Step 2.

It should be noted that although there is an updating of path flow variables in Step 6, this does not require complete path enumeration. Since there is at most one new path per O-D pair per iteration, the computation involved is not excessive.

2.1.3 The Carriers' Submodel

2.1.3.1 Description

Given the values of demand and flow (T_w^{rs}, f_e^{rs}) produced by the shippers' submodel, the carriers' submodel predicts the detailed routing assignments made by the carriers. As such, it uses a detailed description of the transportation network. For modes that control their own right-of-way, such as railroads, the model treats each carrier individually. For the modes that operate on rights-of-way they do not control, such as barges on inland waterways and trucks on highways, the model assumes that the individual carriers that make up the mode behave as a single carrier and that single carrier is then in control of the corresponding portion of the network.

In order to predict an individual carriers' traffic assignment, it is required that the origin-destination demands be known for that portion of the network that the carrier controls. Since the demand from original production origin to ultimate consumption destination, the set of paths that will be used between each O-D pair, and how much of the demand will flow on each path are known from the shippers' submodel, all that is needed is to decompose these paths into the portions used by each carrier.

A typical path P_k^r will be of the form

$$P_k^r = (i, n_1, n_2, \ldots, g_1, n_\ell, n_{\ell+1}, \ldots, g_2, n_n, n_{n+1}, \ldots, j) , \tag{45}$$

where i is the production origin,

n is a node,

g_k is the k^{th} transshipment point of the intermodal network (including railroad gateways), and

j is the consumption destination.

We can represent path P_k^r in general as

$$P_k^r = P_k^{rs_1} + P_k^{rs_2} + P_k^{rs_3} + \ldots , \tag{46}$$

where $P_k^{rs_i}$ is the portion of path P_k^r that uses carrier s_i .

Note that for Equation 45

$$\left.\begin{aligned} P_k^{rs_1} &= (i, n_1, n_2, \ldots, g_1) \\ P_k^{rs_2} &= (g_1, n_\ell, n_{\ell+1}, \ldots, g_2) \\ P_k^{rs_3} &= (g_2, n_n, n_{n+1}, \ldots, j) . \end{aligned}\right\} \tag{47}$$

$$\vdots$$

Given the following definitions,

$h_{P_k}^r$ is the flow on path P_k^r,

$T_w^{rs_i}$ is the demand for commodity r between the terminal points w of carrier s_i, and

P_{ws_i} is the set of all paths which contain O-D pair w as terminal points for carrier s_i,

the following relationship holds:

$$T_w^{rs_i} = \sum_{P_k \varepsilon P_{ws_i}} h_{Pk}^r \tag{48}$$

These $T_w^{rs_i}$ then form the carrier-specific origin-destination demands that enable a systems-optimized traffic assignment problem for each carrier to be constructed. If N_{s_i} is the subset of the network controlled by carrier s_i, this can be expressed by the following mathematical program for carrier s_i:

$$\text{Minimize } Z = \sum_{e\varepsilon N_{s_i}} \sum_r c_e^{rs_i} (f_e) \cdot f_e^{rs_i} = \sum_{p\varepsilon P_{ws_i}} \sum_r c_p^{rs_i} \cdot h_p^{rs_i} \tag{49}$$

subject to $$\sum_{p \varepsilon P_{ws_i}} h_p^{rs_i} = T_w^{rs_i} \quad \forall\ (w,\ r) \tag{50}$$

$$h_p^{rs_i} \geqq 0 \qquad \forall \left(w,\ p\varepsilon P_{ws_i},\ r\right). \tag{51}$$

Solution Algorithm

Although the carriers' submodel is articulated in terms of path flows, it is possible, as was the case with shippers' submodel, to avoid path enumeration. Once again, the Frank-Wolfe algorithm is applied. Its seven-step procedure, as applied to the carrier's submodel, is as follows:

Step 1 Determine an initial feasible solution for the carrier routing problem.

$$\left(\hat{f}_e^{rs_i}\right),$$

where $e\varepsilon N_{s_i}$.

Step 2 For each O-D pair w, determine the shortest path $\tau_w^{rs_i}$ based on element cost $\hat{c}_e^{rs_i}$, where

$$\hat{c}_e^{rs_i} = \frac{\partial}{\partial f_e^{rs_i}} \ c_e^{rs_i}\left(\hat{f}_e\right).$$

Step 3 For all w such that $e\varepsilon\tau_w^{rs_i}$ set $\bar{f}_e^{rs_i} = \sum_w T_w^{rs_i}$.

If $e \not\in \tau_w^{rs}$ for all w set $\bar{f}_e^{rs_i} = 0$.

Step 4 If $\sum_e \sum_r \left[\left(\bar{f}_e^{rs_i} - \hat{f}_e^{rs_i}\right) \hat{c}_e^{rs_i}\right] \leqq \varepsilon$ stop.

Step 5 Compute θ minimizing

$$Z(\theta) = Z\left[f_e^{rs_i} = \hat{f}_e^{rs_i} + \theta\left(\bar{f}_e^{rs_i} - \hat{f}_e^{rs_i}\right)\right]$$

$$= \sum_e \sum_r \left[c_e^{rs_i}\left(\hat{f}_e^{rs_i} + \theta\left(\bar{f}_e^{rs_i} - \hat{f}_e^{rs_i}\right)\right) \cdot \left[\hat{f}_e^{rs_i} + \theta\left(\bar{f}_e^{rs_i} - \hat{f}_e^{rs_i}\right)\right]\right].$$

Step 6 Compute

$$f_e^{rs_i} = \hat{f}_e^{rs_i} + \theta\left(\bar{f}_e^{rs_i} - \hat{f}_e^{rs_i}\right)$$

using θ from Step 5.

Step 7 Update by setting

$$\hat{f}_e^{rs_i} = f_e^{rs_i} .$$

Go to Step 2.

2.2 DISAGGREGATION THEORY AND METHOD

In order to identify with any degree of precision the location of railway links and/or nodes that may prove to be bottlenecks in the rail network due to coal shipments in the period 1985-1991, a detailed rail network model data base has been acquired from the Federal Railroad Administration (FRA) and updated to reflect recent abandonments, to correct discontinuities, and to add missing network links. The updated network is installed on the Argonne National Laboratory computer. This data base consists of codified descriptions of more than 16,000 railroad links, some 5,000 of which are in the Northeast area under study. Each link is described by codes representing its two terminal nodes, which are shared with other links crossing or connecting there. Each node code is tagged with a subcode in the range 1 to 500, which represents the Department of Transportation's (USDOT's) transportation zone in which the node is located. There may be several such nodes in each transportation zone. Thus, the rail network model is identifiably disaggregated to the transportation zone level.

Supply and demand forecasts available from the Data Resources, Inc. (DRI) coal model are, however, much more geographically aggregate. DRI projections for 1985-1991 are based on U.S. Bureau of Mine (USBOM) regional coal production and state or multistate regional coal demand. In order to be integrated with the FRA rail network data base and to be useful in identifying specific potentially congested rail links, these DRI supply and demand forecasts need to be disaggregated to the transportation zone level.

2.2.1 Supply Disaggregation

In DRI's forecasts, coal movements to the Northeast in 1985-1991 are predicted to come entirely from the Northern Appalachian production area. No Western or Midwestern and only minor amounts of Southern Appalachian coal will be consumed in the Northeast in the 1985-1991 period. In addition, not all coal produced in Northern Appalachia will be destined for the Northeast; much of this coal will be shipped to the Midwest or South for consumption. The production of interest is that volume of coal produced in Northern Appalachia that is destined for the Northeast. For the seven different cases studied, these volumes are given (by sulfur range) in Table 2.1. Case names in the table refer to three basic scenarios: Base Case (no FUA Coal); Oil SIP, under which converted plants are subject to current State Implementation Plan air quality standards for oil burning; and NSPS, under which converted plants are subject to the 1971 New Source Performance Standards.

Table 2.1. Coal Supplies (10^3 ton) for the Northeast Region, 1978, 1985, and 1991[a]

	Sulfur Range (% S)						
Case	0-0.64	0.65-1.04	1.05-1.84	1.85-2.24	2.25-3.04	3.05	Total
Base, 1978	3,464	5,196	19,982	34,967	11,639	4,370	79,618
Base, 1985	3,753	12,409	24,849	25,930	15,129	15,092	97,162
Base, 1991	4,647	10,667	48,992	26,698	11,641	23,594	126,239
Oil, 1985	3,753	17,109	24,849	22,830	14,829	18,792	102,162
Oil, 1991	4,647	10,767	48,992	28,898	37,841	31,894	163,039
NSPS, 1985	3,753	16,309	24,749	25,930	12,329	18,892	101,962
NSPS, 1991	4,647	11,067	48,892	27,098	37,141	33,894	162,739

From Data Resources, Inc.

To disaggregate these values to the transportation zones, historical data must be available at a regional level that are a common denominator for both the transportation zone and the USBOM coal production region. This common denominator is the county. County-level data are available for coal production, reserves, and average coal characteristics such as Btu and sulfur content through the USBOM and the Congressional Research Service. These data are used as the basis for the following disaggregation methodology.

The basic assumptions of this model are as follows:

- The Northeast's total share of each Northern Appalachian county's production is limited to an 11% annual increase from 1978 to 1985 or 1991.
- Total annual county production for the Northeast must be no greater than 5% of total county reserves.
- The average sulfur content of all coal delivered to the Northeast by each producer must equal the average sulfur content of coals in that county.
- The coal delivered by all counties to the Northeast must equal the DRI control total for each sulfur class.
- Coal production destined for the Northeast in future years will approximate 1978 levels of the same.

The mathematical description used to implement these assumptions takes the form of a mathematical programming problem. The objective is to minimize deviations from 1978 county production figures while satisfying the conditions stated above, namely:

Minimize
$$\sum_{i=1}^{n} \left(P_i - P_i^o\right) \tag{52}$$

subject to
$$\sum_{i=1}^{n} X_{ij} = S_j \tag{53}$$

$$\sum_{j=1}^{6} a_j X_{ij} - b_i \sum_{j=1}^{6} X_{ij} = 0 \tag{54}$$

$$\sum_{j=1}^{6} X_{ij} - P_i = 0 \tag{55}$$

$$P_i \leqq (1.1)^t * P_i^o \tag{56}$$

$$P_i \leqq 0.05 * R_i \tag{57}$$

$$X_{ij},\ P_i \geqq 0\ , \tag{58}$$

where P_i = county i production destined to Northeast in forecast year,

P_i^o = county i production destined for Northeast in 1978,

X_{ij} = production in county i of sulfur class j destined for the Northeast in forecast year,

S_j = DRI total production in sulfur class j destined for the Northeast in forecast year,

a_j = average sulfur level in sulfur category j,

b_i = average sulfur level of all coals in county i,

t = years from 1978 to forecast year, and

R_i = reserves in county i in 1978.

Using a standard procedure of mathematical programming, this nonlinear program can be converted into an easier-to-solve linear program. This is accomplished by introducing two new sets of variables, Z_i and Y_i, corresponding to the positive difference between P_i and P_i^o, depending on which is the larger. That is,

$$Z_i - Y_i = P_i - P_i^o \quad , \tag{59}$$

and Z_i and Y_i are both nonnegative. It is readily discernable that minimizing $Z_i + Y_i$ always gives the same value as minimizing the absolute value of $P_i - P_i^o$. This is so since when $P_i > P_i^o$, $Z_i = P_i - P_i^o$ and $Y_i = 0$, and when $P_i < P_i^o$, $Z_i = 0$, $Y_i = P_i - P_i^o$ and again the sum of Y_i and Z_i is the absolute value of the difference between P_i and P_i^o.

Adding the definitional Equation 59 to the programming model above and using

$$\text{minimize} \qquad \sum_{i=1}^{n} (Y_i + Z_i) \tag{60}$$

as the objective, one may calculate county production levels P_i for each forecast case. The final step in the disaggregation methodology involves aggregating up from the county to the transportation zone level. This is accomplished easily through the use of a mapping data set that defines the correspondence between counties and transportation zones. It should be noted that it is at this final step that Southern Appalachian production is excluded from further consideration; production from this region is included in the disaggregation process itself.

2.2.2 Coal Demand Disaggregation

Demand for coal is divided into three distinct categories: nonutility demand, utility demand of non-FUA facilities, and FUA demand. Each has its own special disaggregation mechanism. The procedure followed is first to assign the specific coal demands for each FUA plant and then to subtract the FUA demands from the region totals, which are directly available from the DRI output. The remaining or non-FUA coal is then disaggregated to the transportation zone level.

2.2.2.1 DRI Coal Model Demand Output

For each demand region and for each of the six sulfur ranges, the DRI model produces annual coal demand projections broken into two categories: constrained and unconstrained (also called incremental by DRI). Constrained refers to coal accounted for by long-term contracts, and unconstrained is all other or non-contract coal. All FUA coal falls into the non-contract area; however, non-FUA coal is included in both categories.

The total (constrained + unconstrained) DRI demand projections for the Northeast are presented in Tables 2.2 through 2.8. These tables also include the total FUA demand for each region, from USDOE (1981), and the utility percentage of non-FUA demand. The "% Util. Non-FUA" entries were calculated from special DRI outputs prepared for the Base Case that broke down the regional demands into the DRI Consuming Sectors categories (see Appendix A): electrical utility, metallurgical, industrial noncoking, household commercial, and export. All data in Tables 2.2-2.8 are based on 24.1-million-Btu/ton coal, the Northern Appalachia average used by DRI, which differs from the 23-million-Btu/ton assumed value used in USDOE (1981).

DRI's projected non-contract coal demands for the 1991 Oil SIP scenario are presented in Table 2.9. The non-contract demand includes, as previously mentioned, all FUA coal and a portion of the non-FUA coal. The table includes the distribution by sulfur category and indicates the amount and extent of assumed scrubbing. Decisions concerning scrubbing are based entirely on DRI parameters and represent the DRI optimum combination of mine-mouth, transportation, and scrubbing costs to meet emissions standards for each demand region.

The data in Table 2.9 and all subsequent disaggregation discussion are limited to the 1991 Oil SIP scenario because that corresponds to the analysis of FNEM results that is made in Section 6. The year 1991 was selected because all FUA plants are expected to be converted by then. NSPS scenario runs were also made with FNEM, but from the transportation viewpoint, the results did not differ significantly from the Oil SIP because, for the most part, DRI simply assumed additional scrubbing to achieve a low-sulfur scenario.

2.2.2.2 FUA Demand

The next step is to apportion the data in Table 2.9 among the individual FUA plants. This breakdown is presented in Table 2.10. The coal tonnage for each plant is fixed and listed in Table 2.11; however, the assignment by sulfur type is limited only by the DRI region totals. The guideline used was to assign sulfur categories to match as closely as possible the values used in the Northeast Regional Environmental Impact Statement (USDOE 1981). The target assignment for each plant is given in the last column of Table 2.10 as a number from 1 to 6, matching the sulfur type column headings.

2.2.2.3 Non-FUA Demand

After assigning the FUA plant demands as given in Table 2.9, the remaining non-contract coal is combined with the DRI constrained coal to obtain the total non-FUA coal demand by region for each sulfur category. The contract coal demands are readily obtained by subtracting the Table 2.9 DRI region totals from Table 2.8. The final 1991 Oil SIP totals for the Northeast Region are 36.5 and 126.5 million tons, respectively, for FUA and non-FUA coal.

Nonutility (non-FUA) Demand

The breakdown between utility and nonutility non-FUA demand is given in the last column of Table 2.8. Historical data on nonutility coal consumption are available from the U.S. Bureau of Mines at the state level. These data can be further disaggregated to the county level by the use of U.S. Environmental Protection Agency point source consumption data. These data are summed up over counties and states, and the county shares of each state consumption are computed. These county shares are then applied to the DRI nonutility coal demands by state and sulfur category to derive county level estimates. Thus, nonutility coal demand is proportionally allocated to counties based on historical consumption patterns. Demands are then summed over all counties within each transportation zone to produce a total demand by zone.

Utility (non-FUA) Demand

The case of non-FUA utility demand is handled in a similar but not identical manner to that of the nonutility demand. USDOE projections of coal-fired utility generating capacity by county for 1985 and 1990 are used to compute county shares of state coal-fired generating capacity.

Table 2.2. Demand for Coal (10^3 ton) in the Northeast--Base Case, 1978

	Sulfur Range (% S)							
	1[a]	2	3	4	5	6		% Util.
State(s)	0-0.64	0.65-1.04	1.05-1.84	1.85-2.24	2.25-3.04	3.05	FUA	Non-FUA
DE	0	200	0	263	200	0	0	95.69
ME,NH,VT	0	0	200	0	905	100	0	93.99
MD	1,076	671	6,817	1,104	1,981	112	0	29.97
MA	0	100	0	0	0	0	0	0.00
NJ	0	0	1,365	0	1,343	0	0	95.14
NY	1,198	240	5,106	589	4,293	5	0	51.88
PA	1,190	3,985	6,494	33,011	2,917	4,153	0	60.04

From Data Resources, Inc.

[a]Sulfur categories were designated 1 through 6, as shown.

Table 2.3. Demand for Coal (10^3 ton) in the Northeast--Base Case, 1985

	Sulfur Range (% S)							
	1[a]	2	3	4	5	6		% Util.
State(s)	0-0.64	0.65-1.04	1.05-1.84	1.85-2.24	2.25-3.04	3.05	FUA	Non-FUA
DE	0	900	0	155	0	400	0	96.36
ME,NH,VT	0	0	0	400	834	0	0	93.89
MD	2,211	1,321	4,249	2,075	4,238	4,812	0	29.68
MA	0	100	0	0	0	0	0	0.00
NJ	0	1,700	392	0	733	0	0	95.48
NY	229	268	3,176	648	6,416	5,405	0	53.50
PA	1,313	8,120	17,032	22,652	2,908	4,475	0	56.55

From Data Resources, Inc.

[a]Sulfur categories were designated 1 through 6, as shown.

Table 2.4. Demand for Coal (10^3 ton) in the Northeast--Base Case, 1991

	Sulfur Range (% S)							
	1[a]	2	3	4	5	6		% Util.
State(s)	0-0.64	0.65-1.04	1.05-1.84	1.85-2.24	2.25-3.04	3.05	FUA	Non-FUA
CT	0	0	0	0	0	100	0	0.00
DE	0	1,000	0	7	0	700	0	96.35
ME,NH,VT	0	0	0	0	1,124	200	0	93.39
MD	2,747	1,641	2,940	5,977	8,568	4,729	0	37.36
MA	0	100	0	0	100	0	0	0.00
NJ	0	1,800	18	0	33	1,900	0	95.21
NY	282	330	1,481	12,199	83	6,406	0	49.75
PA	1,618	5,796	44,553	8,515	1,733	9,559	0	54.51

From Data Resources, Inc.

[a]Sulfur categories were designated 1 through 6, as shown.

Table 2.5. Demand for Coal (10^3 ton) in the Northeast--Oil SIP, 1985

	Sulfur Range (% S)							
	1[a]	2	3	4	5	6		% Util.
State(s)	0-0.64	0.65-1.04	1.05-1.84	1.85-2.24	2.25-3.04	3.05	FUA	Non-FUA
CT	0	100	0	0	0	2,300	2,345	0.00
DE	0	900	0	155	0	400	0	96.36
ME,NH,VT	0	0	400	0	534	300	0	93.89
MD	2,211	1,321	4,249	2,075	4,938	4,112	0	29.68
MA	0	100	0	0	0	0	0	0.00
NJ	0	1,700	392	0	733	0	0	95.48
NY	229	6,468	3,176	648	6,816	805	2,014	53.50
PA	1,313	6,520	16,632	19,952	1,808	10,875	0	56.55

From Data Resources, Inc.

[a]Sulfur categories were designated 1 through 6, as shown.

Table 2.6. Demand for Coal (10^3 ton) in the Northeast--Oil SIP, 1991

	Sulfur Range (% S)							
	1[a]	2	3	4	5	6		% Util.
State(s)	0-0.64	0.65-1.04	1.05-1.84	1.85-2.24	2.25-3.04	3.05	FUA	Non-FUA
CT	0	0	0	0	500	2,600	3,003	0.00
DE	0	0	0	7	1,700	800	838	96.35
ME,NH,VT	0	0	0	1,800	224	200	842	93.39
MD	2,747	1,641	2,940	4,977	14,568	4,629	4,873	37.36
MA	0	5,200	0	100	0	0	5,085	0.00
NJ	0	0	18	0	2,733	5,900	4,907	95.21
NY	282	1,930	1,481	12,899	15,183	3,406	14,233	49.75
PA	1,618	1,996	44,553	9,115	2,733	14,259	2,475	54.51
RI	0	0	0	0	200	100	291	0.00

From Data Resources, Inc.

[a]Sulfur categories were designated 1 through 6, as shown.

Table 2.7. Demand for Coal (10^3 ton) in the Northeast--NSPS, 1985

	Sulfur Range (% S)[a]							
	1[a]	2	3	4	5	6		% Util.
State(s)	0-0.64	0.65-1.04	1.05-1.84	1.85-2.24	2.25-3.04	3.05	FUA	Non-FUA
CT	0	500	0	0	0	1,900	2,345	0.00
DE	0	900	0	155	0	400	0	96.36
ME,NH,VT	0	300	0	0	534	400	0	93.89
MD	2,211	1,921	8,049	2,075	4,238	312	0	29.68
MA	0	100	0	0	0	0	0	0.00
NJ	0	1,700	392	0	733	0	0	95.48
NY	229	2,168	9,276	648	5,016	805	2,014	53.50
PA	1,313	8,720	7,032	23,052	1,808	15,075	0	56.55

From Data Resources, Inc.

[a]Sulfur categories were designated 1 through 6, as shown.

Table 2.8. Demand for Coal (10^3 ton) in the Northeast--NSPS, 1991

	Sulfur Range (% S)[a]							
	1[a]	2	3	4	5	6		% Util.
State(s)	0-0.64	0.65-1.04	1.05-1.84	1.85-2.24	2.25-3.04	3.05	FUA	Non-FUA
CT	0	0	0	0	0	3,000	3,003	0.00
DE	0	0	0	7	1,800	700	838	96.35
ME,NH,VT	0	0	0	1,100	24	1,100	842	93.39
MD	2,747	8,741	2,940	5,277	7,068	4,729	4,873	37.36
MA	0	0	0	0	3,700	1,600	5,085	0.00
NJ	0	0	18	0	8,133	500	4,907	95.21
NY	282	330	4,881	10,199	15,983	3,406	14,233	49.75
PA	1,618	1,996	41,053	10,515	233	18,759	2,475	54.51
RI	0	0	0	0	200	100	291	0.00

From Data Resources, Inc.

[a]Sulfur categories were designated 1 through 6, as shown.

Table 2.9. Projected Non-Contract Coal Demand for the Northeast Region, Oil SIP, 1991

State(s)	Sulfur Content (%)	Demand Distribution (10^6 ton) Unscrubbed	Scrubbed	% Sulfur Removal
Maine, New Hampshire,	1.85 - 2.24	1.8		
Vermont	2.25 - 3.04		0.2	70
	3.05 - >		0.2	90
Pennsylvania	1.05 - 1.84	35.9		
	1.85 - 2.24	3.7		
	2.25 - 3.04		2.5	70
	3.05 - >		4.8	70
	3.05 - >		9.4	90
Connecticut	2.25 - 3.04		0.5	90
	3.05 - >		2.6	90
Massachusetts	0.65 - 1.04	5.2		
	1.85 - 2.24	0.1		
Maryland	1.85 - 2.24	2.4		
	2.25 - 3.04		9.3	70
	3.05 - >		4.6	90
Delaware	2.25 - 3.04		1.7	70
	3.05 - >		0.8	90
Rhode Island	2.25 - 3.04		0.2	70
	3.05 - >		0.1	90
New York	0.65 - 1.04	1.6		
	1.85 - 2.24	12.1		
	2.25 - 3.04		15.1	70
	3.05 - >		3.4	90
New Jersey	2.25 - 3.04		2.7	70
	3.05 - >		5.9	90
Regional total		62.8	64.0	

From Data Resources, Inc., Simulation Conr/OILSTD, 8/20/80, Table 6.

Table 2.10. DRI-Projected Northeast Regional Non-Contract Coal Demands, Oil SIP, 1991

		Annual Coal Demand by Type-% Sulfur[a] (10^3 ton)						NER
		1	2	3	4	5	6	EIS
DRI Region	Demand	0-0.64%	0.65-1.04%	1.05-1.84%	1.85-2.24%	2.25-3.04%	3.05 +%	Sulfur Type[b]
Maine,	Mason				436			6
New Hampshire,	Schiller				406			3
Vermont	All non-FUA				958	200	200	
Regional total					1,800	200	200	
Pennsylvania	Cromby						424	6
	Schuylkill						374	6
	Southwark						1,159	6
	Springdale						518	6
	All non-FUA			35,900	3,700	2,500	11,725	
Regional total				35,900	3,700	2,500	14,200	
Connecticut	Bridgeport Harbor					145	728	6
	Devon					72	359	6
	Norwalk Harbor					109	546	6
	Montville					38	189	6
	Middletown					136	681	6
	All non-FUA						97	
Regional total						500	2,600	
Maassachusetts	New Boston		1,620					6
	Mystic		957					6
	Canal		1,059					3
	Mount Tom		285					3
	Salem Harbor		689					6
	Somerset		248					3
	West Springfield		227					3
	All non-FUA		115		100			
Regional total			5,200		100			
Maryland	Brandon Shores					3,035		6
	Riverside					361		6
	Crane					859		6
	Wagner					618		6
	All non-FUA				2,400	4,427	4,600	
Regional total					2,400	9,300	4,600	
Delaware	Edge Moor					838		6
	All non-FUA					862	800	
Regional total						1,700	800	
Rhode Island	South Street					200	91	6
	All non-FUA						9	
Regional total						200	100	

Table 2.10. (concluded)

DRI Region	Demand	Annual Coal Demand by Type-% Sulfur[a] (10^3 ton) 1: 0-0.65%	2: 0.65-1.04%	3: 1.05-1.84%	4: 1.85-2.24%	5: 2.25-3.04%	6: 3.05 +%	NER EIS Sulfur Type[b]
NY	Danskammer						1,134	6
	Arthur Kill				1,916			3
	Ravenswood				1,680			3
	Barrett					818		5
	Northport (1-3)				2,663			3
	Northport (4)						941	6
	Far Rockaway				275			3
	Glenwood					673		5
	Port Jefferson				1,049			3
	Albany				878			3
	Oswego				992			3
	Lovett					1,214		5
	All non-FUA		1,600		2,647	12,395	1,325	
Regional total			1,600		12,100	15,100	3,400	
NJ	Deepwater						463	6
	Sayreville					344	178	3
	Bergen					752	387	3
	Kearny					346	178	3
	Sewaren					730	377	3
	Hudson					528	273	3
	Burlington						351	6
	All non-FUA						3,693	
Regional total						2,700	5,900	

[a]24.1 million Btu/ton.

[b]From USDOE (1981).

Table 2.11. FUA-Related Coal Demand, 1991[a]

Plant	State	Coal (10^3 ton)
Bridgeport Harbor	CT	873
Devon	CT	431
Norwalk Harbor	CT	655
Montville	CT	227
Middletown	CT	817
State total	CT	3,003
Edge Moor	DE	838
State total	DE	838
Mason	ME	436
State total	ME	436
Brandon Shores	MD	3,035
Riverside	MD	361
Crane	MD	859
Wagner	MD	618
State total	MD	4,873
New Boston	MA	1,620
Mystic	MA	957
Canal	MA	1,059
Mt. Tom	MA	285
Salem Harbor	MA	689
Somerset	MA	248
West Springfield	MA	227
State total	MA	5,085
Schiller	NH	406
State total	NH	406
Deepwater	NJ	463
Sayreville	NJ	522
Bergen	NJ	1,139
Kearney	NJ	524
Sewaren	NJ	1,107
Hudson	NJ	801
Burlington	NJ	351
State total	NJ	4,907
Danskammer	NY	1,134
Arthur Kill	NY	1,916
Ravenswood	NY	1,680
Barrett	NY	818
Northport	NY	2,663
Northport	NY	941
Far Rockaway	NY	275
Glenwood	NY	673
Port Jefferson	NY	1,049
Albany	NY	878
Oswego	NY	992
Lovett	NY	1,214
State total	NY	14,233
Cromby	PA	424
Schuylkil	PA	374
Southwark	PA	1,159
Springdale	PA	518
State total	PA	2,475
South Street	RI	291
State total	RI	291
Regional total		36,547

[a]Based on 24.1 million Btu/ton.

Under the assumption that capacity utilization is uniform within each state, these county shares can be used as proxies for county shares of total non-FUA utility coal consumption. (Also note that 1990 generating capacities are used for the 1991 forecast year.) These county shares are multiplied by DRI state level non-FUA utility demands to produce projected county utility shares. The counties within each transportation zone are then summed to give the zone total.

2.2.3 Disaggregation of Noncoal Commodities

The realistic assessment of the transportation impacts of increased coal haulage requires consideration of noncoal commodities. Disaggregate county level supply and demand forecasts for noncoal commodities were made using the methodogy developed previously by Transportation and Economic Research Associates, Inc. (1979). This methodology is highly similar to the linear-programming-based procedure for coal described in Section 2.2.1.

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3. DESCRIPTION OF DATA BASE

3.1 THE NETWORK DATA BASE

The essence of the network data file is a pairwise interconnected series of nodes designated by unique seven-digit codes. The node pairs in the raw data file, although termed "ANode" and "BNode," do not imply direction. However, in its final form as input to the network algorithm, each ANode and BNode is duplicated and reversed to represent unique directions. These pairs are called "twins". For example, using one-digit rather than seven-digit node codes, a simple circular network of five links and nodes may be represented by the following:

ANode	BNode	Sequence Number	Twins
1	2	1	6
2	3	2	10
3	4	3	9
4	5	4	8
5	1	5	7
2	1	6	1
1	5	7	5
5	4	8	4
3	2	10	2

The U.S. rail network is much more complex, but its representation is the same. In the National Network Data Base (NNDB) there are 15,506 railroad links without duplication for directionality (National Network Data Base, computer tape obtained from the Federal Railroad Administration, December, 1980). The study area encompassed 15 states--Connecticut, Delaware, Kentucky, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, Vermont, Virginia and West Virginia. The number of these links in the region is 5,596. When certain unneeded dummy links and split links were eliminated or consolidated, the rail network was reduced to 2,777 links in that region. These must be doubled, as in the example above, to represent directionality. In addition to railroad links, links representing waterway connections and ports are needed to complete the network description. Logical links also are added to the network to delineate the connection between origins and destinations of traffic within and outside the region. In total, the size of the network is 9,566 links with directionality included. As mentioned in Sections 1 and 2, considerable effort was spent to "clean up" the NNDB. This effort is summarized in Appendix B.

As shown in the example above, each pair of nodes constituting a link is given a sequence number (1 to 9566 in the data base) and is associated with the sequence number of its reversed direction pair. This is to facilitate the computation of costs and delays of incremental traffic level in both directions. On water links and port (transshipment) links, only one direction is specified so the second "pair number" is set equal to zero. Each link also is named with a link identification code (LIC) and associated with several attributes, depending on the type of link. Examples of the various types of links in the network are shown in Figure 3.1. A detailed discussion of each type follows. Figure 3.2 is plot of the entire Northeast freight network without node or link names to give a feeling for the complexity and detail involved.

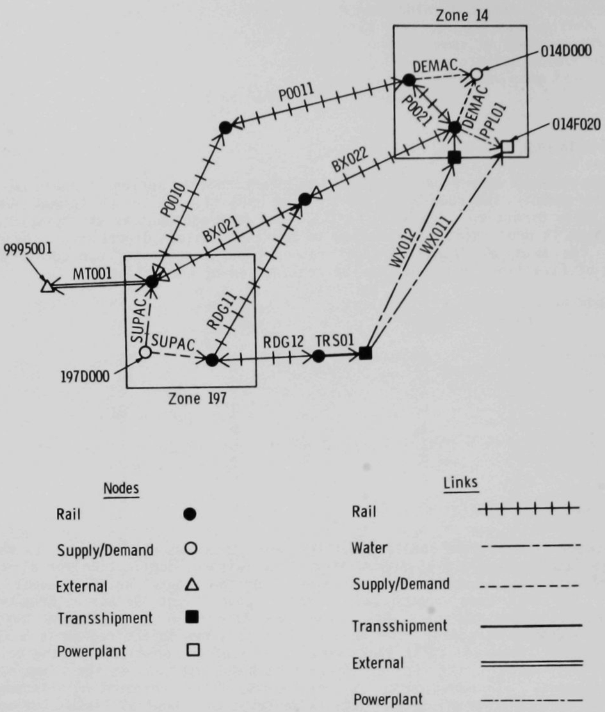

Fig. 3.1. Illustrative Network Links and Nodes

3.1.1 Rail Link Data Description

Each railroad link data record in the network file contains the following 12 data fields:

Field	Data
1-2	Railroad system code
7-11	Link identification code (LIC)
13-19	ANode
21-27	BNode
28-32	Distance
34	Density code
36-37	State code
38	Track code
39	Signal system code
41-42	Free running speed
72-75	Sequential link number
77-80	Reverse link number

3.1.1.1 Railroad Code/LIC

Each five-digit LIC consists of a one- to four-digit alpha code abbreviating the name of the principal operating railroad followed by a unique sequential one- to four-digit number. The railroad codes are given in Table 3.1. Many of the railroad companies in the table have been

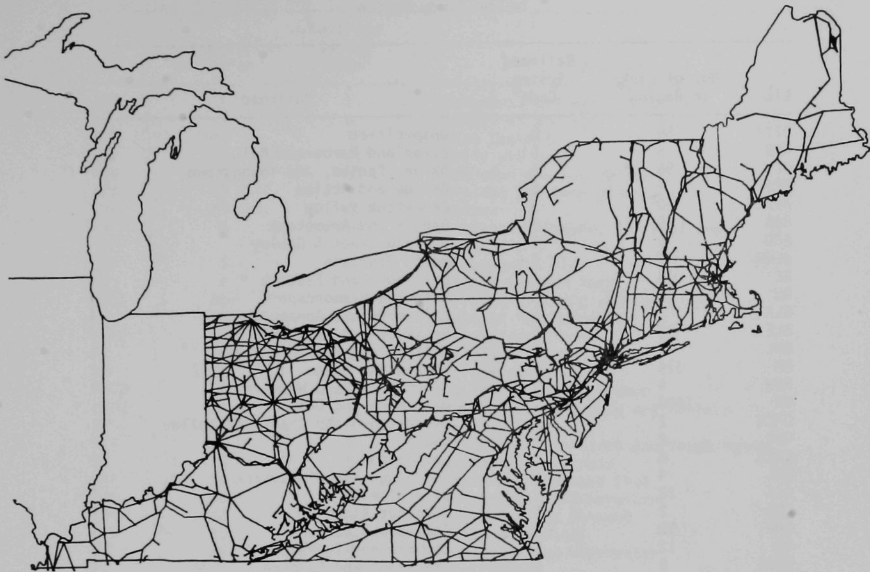

Fig. 3.2. Northeast Regional Rail Network

merged into larger systems. Many others represent small feeder or connecting lines. Because the carriers' model distinguishes between rail systems to optimize routes within the purview of a single management organization, these many old-line railroads have been accumulated into five principal systems important in the region.

Code	Rail System
1	Conrail
2	CSX Corp. (Chessie/family lines)
3	Norfolk and Western
4	Boston and Maine
5	Feeder and connecting lines

The rail system codes assigned to each railroad also are given in Table 3.1. In addition to railroad companies, there are catch-all LIC alpha codes for unspecified and mixed ownership and for aggregated urban links. The latter are necessary to simplify the complexity of a large urban rail network into single node. These have been characterized as feeder and connecting lines, as shown in the table.

Nodes

In the final form of the network the ANode represents an origin for the link and the BNode the destination. Each node code consists of seven digits in three parts. The first three digits

Table 3.1. Federal Railroad Administration National Network Data Base LIC Railroad Designation Codes in the Study Region

LIC	No. of Links in Region	Railroad System Code[a]	Railroad
????	56	5	Unspecified
ABB	8	5	Akron and Barberton Belt
ACY	56	5	Akron, Canton, and Youngstown
ARA	2	5	Arcade and Attica
AVL	10	5	Aroostook Valley
BAR	96	5	Bangor and Aroostook
BCG	2	5	Buffalo Creek & Gauley
BEEM	2	5	Beech Mountain
BE	14	1	Baltimore and Eastern
BH	2	5	Bath and Hammondsport
BLA	2	5	Baltimore and Annapolis
BLE	62	5	Bessemer and Lake Erie
BML	2	5	Belfast and Moosehead Lake
BM	374	4	Boston and Maine
BRW	4	5	Black River and Western
BX	1008	2	Baltimore and Ohio
CACV	2	5	Cooperstown and Charlotte Valley
CAD	2	5	Cadiz
CARR	6	5	Carrollton
CBL	4	5	Conemaugh and Black Lick
CCX	28	2	Clinchfield
CHR	2	5	Chestnut Ridge
CHW	10	5	Chesapeake Western
CI	12	5	Cambria and Indiana
CLCX	6	5	Claremont and Concord
CLP	8	5	Clarendon and Pittsford
CNJ	102	1	Central Railroad of New Jersey
CNY	4	5	Central New York
CN	4	5	Canadian National
CP	30	5	Canadian Pacific
CV	88	5	Central Vermont
CX	646	2	Chesapeake and Ohio
DH	168	5	Delaware and Hudson
DTI	66	5	Detroit, Toledo and Ironton
EEC	4	5	East Erie Commercial
EL	684	1	Erie Lackawanna
FCIN	2	5	Frankfort and Cincinnati
FJG	2	5	Fonda, Johnstown and Gloversville
FOR	2	5	Fore River Railroad
FPE	4	5	Fairport, Painsville and Eastern
GJ	2	5	Greenwich and Johnsonville
GMRC	4	5	Green Mountain
GNWR	4	5	Genessee and Wyoming
GTE	48	5	Grand Trunk
GU	12	5	Grafton and Upton
IC	104	5	Illinois Central Gulf
IRN	2	1	Ironton
KCNW	2	5	Kelly's Creek and Northwestern
KT	2	5	Kentucky and Tennessee
KYLE	2	5	Kyle Railways
LAL	2	5	Livonia, Avon and Lakeville
LAWV	4	5	Lorain and West Virginia
LEE	4	5	Lake Erie and Eastern
LEF	10	5	Lake Erie, Franklin and Clarion
LHR	16	1	Lehigh and Hudson River
LI	66	5	Long Island
LNE	18	1	Leheigh and New England
LN	354	2	Louisville and Nashville
LT	4	5	Lake Terminal
LV	354	1	Leheigh Valley

Table 3.1. (concluded)

LIC	No. of Links in Region	Railroad System Code[a]	Railroad
LWV	4	1	Lackawanna and Wyoming Valley
MB	2	5	Montpelier and Barre
MEC	144	5	Maine Central
MGA	46	5	Mobile and Gulf
MNJ	2	5	Middleton and New Jersey
MPA	12	5	Maryland and Pennsylvania
MTR	24	5	Montour
MW	4	5	Chicago, Milwaukee, St. Paul and Pacific
NAP	2	5	Narragansett Pier
NB	4	5	Northampton and Bath
NFD	30	5	Norfolk, Franklin and Danville
NH	14	5	State of New Hampshire
NIAJ	2	1	Niagara Junction
NS	10	5	Norfolk Southern
NW	1074	3	Norfolk and Western
NYLB	16	1	New York and Long Branch
NYSW	24	5	New York, Susquehanna and Western
NYS	2	5	New York State
PCY	2	5	Pittsburgh, Chartiers and Youghioghen
PI	10	5	Paducah and Illinois
PLE	56	5	Pittsburgh and Lake Erie
PRS	68	1	Penn-Reading Seashore Line
PS	20	5	Pittsburgh and Shawmut
PTM	16	5	Portland Terminal
PW	40	5	Providence and Worchester
P	3072	1	Penn Central
QC	4	5	Quebec Central
RDG	298	1	Reading
RFP	22	5	Richmond, Fredericksburg and Potomac
RR	6	5	Raritan River
RV	8	5	Rahway Valley
SCM	2	5	Strouds Creek and Muddlety
SIRC	18	2	Staten Island Railroad Corp.
SJL	8	5	St. Johnsbury and Lamoille Co.
SPT	12	5	Septa
SRC	2	5	Strasburg
STRT	2	5	Stewartstown
ST	4	5	Springfield Terminal
SZ	80	2	Seaboard Coast Line
S	202	5	Southern
TAW	2	5	Toledo, Angola and Western
TPT	2	1	Trenton-Princeton Traction
UBN	6	5	Aggregated Urban Line
URR	4	5	Union RR-Pittsburgh
USG	34	5	United States Government
VBR	2	5	Virginia Blue Ridge
VTR	26	5	Vermont
WAW	4	5	Waynesburg and Washington
WLFB	2	5	Wolfeboro
WM	182	2	Western Maryland
WNFR	2	5	Winifrede
WNF	2	5	Winfield
WVN	4	5	West Virginia Northern
WW	2	5	Winchester and Western
XX	320	5	Mixed Owners
YS	15	5	Youngstown and Southern

*Dummy links were eliminated.

[a]System Codes: 1=Conrail, 2=CSX Corp., 3=Norfolk & Western, 4=Boston & Maine, 5=feeder & connecting lines

correspond to the Transportation Network Zone defined by the Federal Railroad Administration for network modeling efforts. The zones in the study region are shown in Figure 3.3. The fourth digit indicates the type or class of the node as follows:

Code	Class
1, 2	Logical
5, 6, 7	Physical
8, 9	Dummy

Physical nodes represent places where tracks intersect. These may be yards, terminals, or just switches. Logical nodes constitute an arbitrary designation either halfway between two physical nodes or a point on the zone border between two physical nodes. Logical nodes also represent a stub end of track. These are included in the original network as loading and unloading points for all freight stations along the link but not at the physical node. Finally dummy nodes were used primarily to reduce to a maximum of four the number of links intersecting at any node. Because of software limitations early in FRA's development of the network (they were using an adapted highway network algorithm), certain urban areas where many rail links converge required several "satellite" dummy nodes to consolidate incoming links in to four links reaching the physical nodes. All of these links are represented by zero distance. One other use of dummy nodes is as an arbitrary halfway point between two logical nodes. This occurs when a length of track passes through a zone without intersecting any other track or without terminating. Since logical nodes are used to show where the track crosses zone boundaries, a dummy node takes the place of the missing physical nodes inside of the zone. This does not occur very often because the zones were drawn to correspond to railroad junctions. All of these various levels of nodes are not needed for the FNEM. The FNEM suffers from no limitation as to the number of links that may terminate at a node. Further, since traffic detail does not reach the freight station level, the logical nodes are not needed, either. Programs were developed to eliminate and consolidate unnecessary links ("REDUCE" program eliminates dummy nodes; "SHORTEN" program eliminates logical nodes). These programs reconstruct the network based on links between physical nodes. Since all dummy and logical nodes do not fit the same pattern, some remain in the final network. However, the only harm these cause is a small increase in the dimensions of the problem. Further work will analyze these on a case-by-case basis to determine whether any more efficiencies may be obtained by reducing the number of links necessary to describe the actual railroad system.

The last three digits are simply a sequential counter for nodes of a given type within a zone and serve to make the node code unique.

Another program was used to make the network bidirectional by duplicating each link and reversing the ANode with the BNode.

Other Descriptive Data

Other data related to each link include the standard two-digit alpha code for the state in which the link is located and the following operating data:

- Distance between nodes in tenths of a mile

- A code for track configuration

  0 = stub end, number of tracks unknown
  1-7 = actual number of tracks
  8 = ferry service
  9 = through track, number unknown
  blank = unknown

- A code for signal system

  0 = no signalling
  1 = automatic blocking system
  2 = centralized traffic control
  5 = aggregated urban link
  8 = ferry service

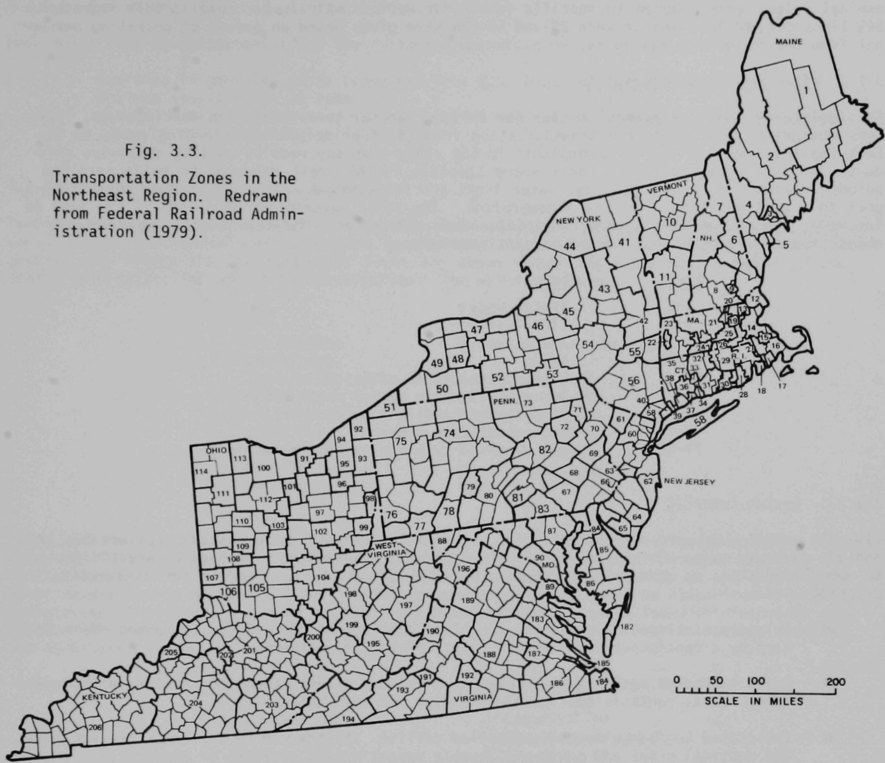

Fig. 3.3.

Transportation Zones in the Northeast Region. Redrawn from Federal Railroad Administration (1979).

- A code representing two-way traffic density in millions of tons per year

  1 = < 1
  2 = ≧ 1, < 5
  3 = ≧ 5, <10
  4 = ≧10, <20
  5 = ≧20, <30
  6 = ≧30

The density values were determined by survey of the railroad's traffic levels for average traffic during the years 1972 through 1976, with some updates through 1979 (personal communication with Raphael Keder, FRA).

All of the data described above were obtained in tape form from the FRA. One additional needed variable was omitted from the tape for reasons of confidentiality. Free running speed is an important characteristic of rail links in the network that was obtained by independent research. Due to the size of the problem (i.e., number of links), some simplifying assumptions were necessary. Based on discussions with operating personnel at Conrail, Chessie, and Southern Railways, a nominal speed of 25 mph was assigned to all Conrail, Chessie and affiliated links. Also assigned 25 mph were Seaboard Coast Line, Louisville and Nashville, Main Central and Grand Trunk links. Southern Railway links and all other links were given a nominal value of 20 mph. These nominal values were changed to specific values for various mainlines. In all, this represents 641 links for which values between 25 and 50 mph were given based on survey of operating personnel from the respective railroads.

3.1.2 Water Link Data Description

To complete the major line-haul routes for delivering coal to northeastern destinations, links were designated for waterborne transportation from eight principal coal loading ports on the East Coast to each of the 37 powerplants in the study that may receive coal by coastwise shipment, and to 17 coal receiving ports where possible further rail shipment is built into the network design. In Figure 3.1, two water links are illustrated. They are one-way links from a port to a port and from a port to a powerplant. The basic description of a link is the same as for rail, consisting of a system code, LIC, ANode, BNode, and distance. Other important variables also are given in each record, as outlined below:

Field	Data
1-2	System code
7-11	LIC
13-19	ANode
21-27	BNode
28-32	Distance (nautical miles)
34-35	Maximum allowable vessel draft (ft)
38-41	Origin port loading rate (ton/hr)
72-75	Sequential link number
77-80	Set equal to zero (no reverse direction)

3.1.2.1 System Code/LIC

LICs for water links are designated WX, WY, or WZ. The corresponding system codes are 11, 12, and 13, respectively. The system codes were added for programming convenience to avoid having to translate alpha to integer variables. Each code stands for a class of vessel service, described below.

WX - Inland or intracoastal waterway barge/towboat system. Restricted to routes characterized by a continuous intracoastal (i.e., protected) waterway.

WY - Ocean tug/barge system. Restricted to distances greater than 150 nautical miles where intracoastal route is available; otherwise not restricted.

WZ - Integrated tug/barge or self-propelled collier. Restricted to distances greater than 150 nautical miles and maximum allowable vessel drafts of 30 ft or greater.

Within each class of service, links are numbered sequentially. The class designation is important for computation of costs, which vary by class of service, distance, and vessel size. In the cost functions used, vessel sizes were allowed to vary based on maximum allowable draft for the ocean tug/barge system only. A standard vessel was assumed for each of other two classes.

3.1.2.2 Nodes

Because origin ports and destination ports are well defined, a reverse flow of coal is not feasible along any given water link. Therefore, unlike the rail network, there are no duplicate reversed ANode-BNode links. The nodes for all water links are in addition to the railroad nodes. If they are connected to the railroad, as all ANodes and some BNodes are, they are connected by a transshipment link (see below). The convention adopted for designating nodes is similar to the rail network: the first three digits indicate the zone in which the water terminal is located; the fourth digit is set equal to six for the water end of the transshipment link or set equal to "F" if the destination is a FUA powerplant conversion candidate; the last three digits are sequential by node and make each code unique. (Transshipment links and powerplant nodes are explained further below.)

3.1.2.3 Operational Data

Each water link is characterized by the following operating data:

- Distance in nautical miles (computed from U.S. Dept. of Commerce [1978])
- Maximum vessel draft in feet*
- Vessel loading rate at the original port in tons per hour (adapted from information given by Nielsen [1980, pp. 202-228])

3.1.3 Transshipment Link Data Description

Transshipment links were created to integrate port activities into the network. Eight origin ports and 17 destination ports are given in the model to connect the rail system with the water system. In Figure 3.1, transshipment links are shown connecting railroads to ports at the origin of a water link and at the destination. The origin ports are:

Pier	Location
Port Reading	Woodbridge Township, NJ
Nonexistent expansion port	South Amboy, NJ
Greenwich	Philadelphia, PA
Port Richmond	Philadelphia, PA
Curtis Bay	Baltimore, MD
Canton Pier	Baltimore, MD
C&O Pier	Newport News, VA
Lamberts Point	Norfolk, VA

These were selected on the basis of their present and potential contribution to domestic waterborne coal trade. The "expansion port" was permitted based on speculation about new coal piers in the area and to permit the analysis of important potential bottlenecks on the intracoastal water network at origin ports. Destination ports were selected based on historical flows, rail connections, and proximity to markets not adequately served by established or historical coal ports. The specific pier is not identified. Quite possibly new facilities must be provided. The destination port cities are:

Bangor, ME	New Haven, CT
Searsport, ME	Albany, NY
Portland, ME	Catskill, NY
Portsmouth, NH	Poughkeepsie, NY
Beverly, MA	New York, NY
Salem, MA	Newark, NJ
Lynn, MA	Philadelphia, PA
Boston, MA	Wilmington, DE
Baltimore, MD	

Each transshipment link record has 10 fields if it is a destination port and 13 fields if it is an origin port, as outlined below:

Destination Port:

Field	Data
1-2	System code (=21)
7-11	LIC ("TRS")
13-19	ANode (dock)
21-27	BNode (rail connection)
31-32	Unloading charge (¢/ton)
36-37	State code
38-39	Water depth (feet)
47-63	Port name
72-75	Link sequence number
77-80	Set equal to zero (no reverse direction)

---

*Set equal to the lesser of water depths at the origin or the destination. Water depths taken from the following sources as applicable: U.S. Army Corps of Engineers (1978); Nielsen (1980); U.S. Geological Survey, Reston, Va., 7.5 Minute Series Topographic Maps; National Oceanic and Atmospheric Administration, National Survey, Navigation Charts; and Transportation and Economic Research Associates, Inc. (1981).

Origin Port:

Field	Data
1-2	System code (=21)
7-11	LIC ("TRS")
13-19	ANode (rail connection)
21-27	BNode (dock)
31-32	Dumping charge (¢/ton)
36-37	State code
38-39	Water depth (ft)
43-45	Operating railroad
47-63	Port name
64-66	1985 planned capacity (10^5 ton/yr)
68-70	1980 actual practical capacity (10^5 ton/yr)
72-75	Link sequence number
77-80	Set equal to zero (no reverse direction)

3.1.3.1 System Code/LIC

The LIC used for transshipment link is of the form "TRSXX," where XX is a unique number for each port. The system code of "21" was used for programming convenience.

3.1.3.2 Nodes

A node on the rail network most representative of the actual rail connection to the port was selected as one terminus of the link--the ANode for origin ports and the BNode for destination ports. A code was devised for the other terminus of the link--the dock--which is similar to the rail node except that the number six was used in the fourth digit and the counter was changed if more than one dock was to be represented as connecting to the railroad at one point. These "dock" nodes became the terminal nodes of the water links.

3.1.3.3 Operating Data

The following characteristics are given to facilitate analysis of the network:

- Dumping charge assessed by the port or operating railroad for use of the pier. Conrail operated ports presently assess no dumping charges. B&O, C&O, and N&W piers are given actual dumping charges as quoted by the respective railroads. Since the "expansion port" at South Amboy (if it is built) probably will not be owned or operated by a railroad, it was given a dumping charge of 50 cents, which is higher than the 30-50 cents dumping charges at railroad ports.

- Water depth in feet obtained from the sources cited above for the water links. These duplicate the water link data. The lesser of the water depths at either end of the water link were put as data in the water link network record for programming convenience.

- 1980 practical capacity (much less than design capacity) and 1985 planned capacity are given as parameters for delay functions in the networks solution model. (Compiled by Transportation and Economic Research Associates, Inc. [1981, p. 72].) Values are given in 10^5 ton/yr.

3.1.4 Powerplant Link Data Description

Links were created to connect each powerplant with a rail node that best represents its actual rail connection. This was done to characterize powerplants by unique nodes that are not part of the rail system. Water links may terminate directly at a powerplant node and so do not require a special link as do rail connections. The powerplant link is characterized by a zero distance and only one possible direction of flow from the railroad to the plant, as illustrated in Figure 3.1. This prevents the model software from interpreting a powerplant with both rail and water service as a transshipment point where coal may move from water to rail or vice-versa through the plant. Both water links and powerplant links terminate at a plant; they never originate at a plant. Powerplant links are characterized by six fields, as follows:

Field	Data
1-2	System code (X5)
7-11	LIC ("PPLXX")
13-19	ANode (rail connection)
21-27	BNode (plant node)
32	Zero distance
36-37	State code

3.1.4.1 System Code/LIC

The system code convention sets the first digit equal to the major rail system (i.e., one to five) by which the plant is served, and the second digit equal to five. The LIC is always "PPLXX," where XX is a unique number for each plant. Since there are 31 plants with rail connections, there are only 31 such links in the model.

3.1.4.2 Nodes

Rail nodes were chosen as the most representative, nearest node on the actual rail link to serve the plant and located within the zone that the plant is in. Powerplant nodes are characterized by the letter "F" in the fourth digit of the node. The first three digits are the zone and the last three were chosen to match the rail nodes last three digits.

3.1.5 Supply and Demand Link Data

Every zone within the 15-state study region (see Fig. 3.3) is given a supply/demand node for coal and for noncoal commodities. (The present version of the model does not use the noncoal links because these traffic allocations were handled differently than originally planned.) These links are needed to allow access to the network of coal supply and demand totals specified at the transportation zone level. The model was permitted to select the physical loading points within each zone by providing one artificial node within each zone as the locus of the supply or the demand for coal. This artificial node was connected by supply/demand access links to each of the physical nodes (rail nodes with the fourth digits having the values of five, six or seven) in the zone, as illustrated in Figure 3.1. Six fields delineate these links:

Field	Data
1-2	System code
7-11	LIC
13-19	ANode
21-27	BNode
72-75	Link sequence number
77-80	Set equal to zero (no reverse flow allowed)

3.1.5.1 System Code/LIC

Noncoal links for supply and demand are given LICs of SNCOL and DNCOL, respectively. The system codes are respectively 33 and 34. Coal access links for supply and demand are given the LICs of SUPAC and DEMAC and system codes of 31 and 32, respectively.

3.1.5.2 Nodes

For noncoal demand access links the B Node is designated by the zone number (ZZZ) in the form ZZZDNCL. For coal demand access links the form of the node is ZZZD000. The A Node on demand access links is a physical railroad node giving direction from the railroad to the demand.

Supply and demands for coal or noncoal originate/terminate at the same respective nodes, so the designations ZZZDNCL and ZZZD000 also are used for supply. However, supply links have the supply node as the A Node (or origin) and a physical rail node as a B Node (or destination).

3.1.6 External Access Link Data

External access links were provided to bring traffic into and out of the Northeast region so that the model could be executed without making a detailed link-by-link analysis outside the region. They connect five external rail regions with each physical node on the border of the

15-state study region where there are external track links. An example is given in Figure 3.1. There are seven data fields in each link record:

Field	Data
1-2	System code (=6)
7-11	LIC
13-19	A Node
21-27	B Node
28-32	Distance
72-75	Link sequence number
77-80	Reverse link sequence number

3.1.6.1 System Code/LIC

One system code, 6, is given for external links. Five LIC classes are given for links from or to each of the five Railroad Rate Territories for which commodity flow statistics are assembled (see Fig. 3.4). The LICs for each territory are:

LIC*	Territory
MTXXX	Mountain-Pacific
WTXXX	Western trunk line
SWXXX	Southwestern
SOXXX	Southern
OFXXX	Official

*XXX a sequential number making each link unique.

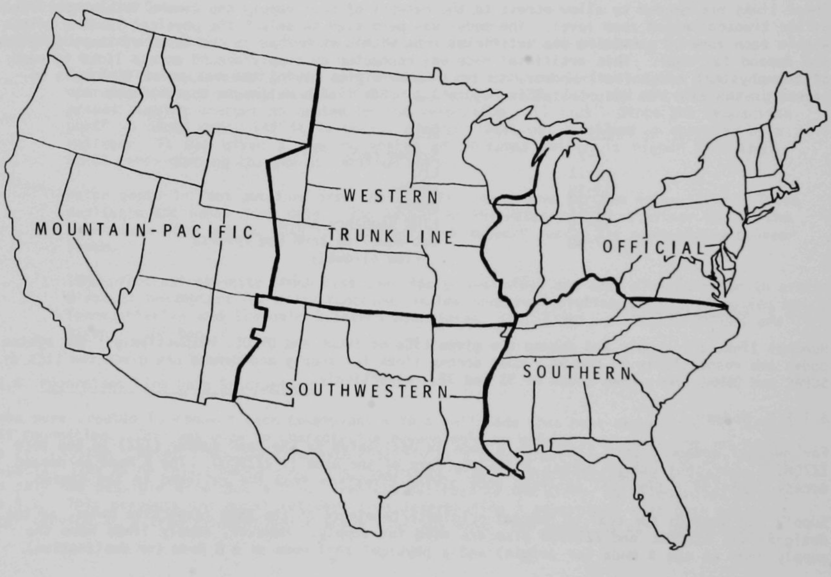

Fig. 3.4. Railroad Rate Territories. Modified from Federal Railroad Administration (1979).

3.1.6.2 Nodes

Each railroad territory is given a unique node to represent it in the network. They are of the form 999500X where X equals one through five for MT, WT, SW, SO, and OF, respectively. The links are bidirectional: incoming links have the territory node as the A Node and a physical rail node as the B Node; outgoing links are reversed. The link sequence number and its reversed pair indicate to the model's software which links must be added to obtain total traffic.

3.1.6.3 Distance

A distance for each link is given in tenths of a mile from a centroid in each territory.

3.2 THE DISAGGREGATION DATA BASE

In Section 2, the base coal supply/demand projections and alternative FUA scenarios were presented along with a discussion of a method for dividing regional and state totals for coal supply and demand into transportation zones as shown in Figure 3.3. The DRI regions for which coal supply and demand is reported and the transportation zones share county boundaries as a common regional denominator. A geocode converter file was used to establish the necessary geographic correlation. A description of this file is followed by descriptions and sources of county level data used to disaggregate regional aggregates to the county level for both supply and demand.

3.2.1 Geocode Converter File

All counties in the U.S. are given a unique five-digit Federal Information Processing Standard (FIPS) code. The first two digits are an alphabetic sequence code for the 50 states, Washington, D.C., Puerto Rico, and other U.S. territories. The latter three digits designate counties and independent cities in alphabetical sequence. A file, FIPSZONE by name, lists, for each FIPS Code in the region, the Transportation Zone number in which the county is located. The state by county correlation is imbedded in the FIPS code. Since only one supply district for coal is applicable from the DRI supply inputs no supply region correlation is necessary. Geocodes were taken from National Geocoding Converter File 1 (La Tores 1974). (State and county names, FIPS codes, and BOM districts are contained in the file COUNTY.DATA.)

3.2.2 Supply Data

Two files describe coal production and distribution in 1978: COUNTY.COAL78 and FLOWS.NE78. The data files in these files are explained in Section 4. The file, COUNTY.COAL78, has data from two sources:

- County level production of coal for years 1975 through 1978 (fields 1-6) was obtained from USDOE (1975-1978).

- Sulfur, heating value (Btu's) and demonstrated reserves (fields 7-9) were obtained from a study performed by The Surface Mining Research Library (1977).

The file FLOWS.NE78 contains information as to the quantity of coal from the BOM districts of Northern and Southern Appalachia that is destined for the Northeast. These data were obtained from the 1978 volume of USDOE (1975-1978).

Additional data for specifying the coal production forecasts to be disaggregated to transportation zone are needed and specified in a file called DRISUPP. This file contains the forecast case name, year and total applicable production. The data are from special runs of the DRI Coal Model (see Table 2.1).

3.2.3 Demand Data

Data specifying local shares of state-level projections differ in type and source between the 42 powerplants being studied for coal conversion (FUA coal) and all other demands for coal (non-FUA coal). Demand projections to be disaggregated were provided from the DRI Coal Model (see Tables 2.2 through 2.8).

3.2.3.1 Non-FUA Coal Demand

The data files used in this disaggregation (NONUTIL.SHARE and UTIL85.SHARE or UTIL95.SHARE) were developed by Transportation and Economic Research Associates, Inc. (1979) for the National Energy Transportation Study (NETS). These files indicate the proportion of projected state-level demand expected to occur in each county in the state. Non-utility demands at the county level are based on the U.S. Environmental Protection Agency's (USEPA) point source data file. This file contains information on every significant fuel-using installation in the country indicating the amounts of what types of fuel were used. This is part of USEPA's National Emissions Data

System. Coal usage by sources other than utilities in 1976 was used to create county proportions of a state total. No shifts in coal usage between counties were examined for the forecast years.

The relative shares of utility plant coal consumption by county within each state are based on information maintained by the Federal Energy Regulatory Commission (FERC). A data file, F12E-2, is kept up to date by FERC with data supplied by the electric utility industry. This file indicates present and expected plant locations, dates for commencement of service, types of fuel used, and generating capacity. This information was used to develop county shares of state-level coal-fired generating capacity for 1985 and 1990, which were used to estimate shares of projected statewide utility consumption of coal.

3.2.3.2 FUA Coal Demand

Argonne National Laboratory (ANL) had made estimates of coal requirements at each of the 42 powerplants under study. ANL also projected a schedule for conversions beginning with five plants in 1985 and to be completed with all 42 converted in 1991. The coal demands projected by ANL were used to establish shares for the FUA coal projected by DRI. Details on coal demand by four categories, utility other than FUA, FUA, nonutility and export, were provided by DRI.

3.3 COST FUNCTIONS

3.3.1 Rail Cost Functions

Rail line haul costs can be subdivided into two types: (1) delay cost, and (2) operating cost (in dollars). Delay cost is the product of the travel time and the value of time. To calculate its value one needs to know both of these factors. Delay can be encountered in both line haul and yard operations. FRA data on the location of relevant classification yards were not obtained and analyzed in time for inclusion in this phase of the analysis; thus, it was not possible to include yard delay in the current formulation of the model. Phase III of this project includes the location of the yards on the FRA network. Operating cost is the actual dollar value of cost incurred by the railroad.

3.3.1.1 Travel Time

The travel delay of freight shipments by rail is a very complex process. Unlike automobile traffic, where drivers have no idea of the desires or actions of other drivers, rail movements are composed of an interdependent set of actions by many different participants. That there is no universally accepted concept of how rail lines congest is not, therefore, very surprising. It is even possible that increasing usage of a rail facility may actually decrease the average travel time over certain flow regimes. This would be the case, for example, when trains are only dispatched when a minimum amount of freight is assembled. The greater the flow, the sooner the minimum freight level is met and the shorter the waiting delay. In addition, each shipment of freight requires a return shipment of empties. The travel delay functions used in this study are based on the arc time functions presented in Bronzini (1979). This model was chosen because it has already been applied to a national freight model in the NETS and because of its ease in implementation. It requires minimum data and presents an aggregate picture. Excessive data and time requirements posed by other models described in Appendix C made them impossible to use, even though the model given by Peterson (1974) is superior to the one given by Bronzini (1979).

The arc time function can be defined as a hyberbolic function over a certain range of arc flow (0-95% of capacity) and an increasing tangential straight line thereafter. The function form used is:

$$t(f_a) = t_0 + \frac{(t_1 - t_0)f_a}{F - f_a} l_a \qquad 0 \leq f_a \leq 0.95F \tag{1}$$

and

$$t(f_a) = [c_a + S_a f_a] l_a \qquad 0.95 \leq f_a \leq F , \tag{2}$$

where t_0 = travel time at traffic levels,

t_1 = travel time at 0.5F,

$t(f_a)$ = arc travel time in hours at traffic volume f_a,

f_a = volume of traffic in 10^7 tons,

l_a = length of the arc in miles,

F = capacity, maximum flow volume in 10^7 tons,

c_a = constant, intercept of slope line of Equation 1 at $f_a = 0.95F$.

S_a = slope of function given in Equation 1 at $f_a = 0.95$.

Figure 3.5 illustrates the above terms clearly. The difference between this function and that of the Bronzini (1979) model lies in the range 0.95F to F. The Bronzini model uses constant arc travel time between these flows. For this study, it has been changed to a straight line increasing function given as in Equation 2.

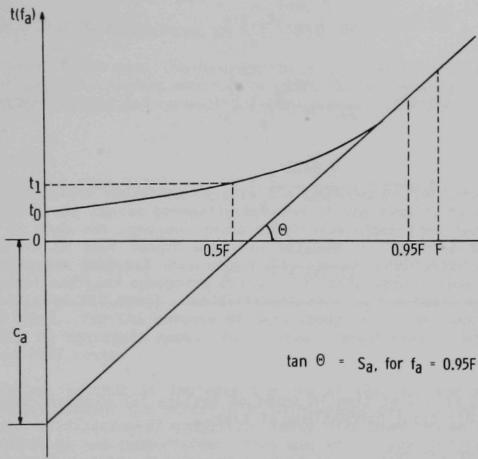

Fig. 3.5. Functional Form of Arc Travel Time Function

Yard delay in this version of FNEM is modeled through a user-specified constant, either as zero--especially for unit trains--or as some nonzero average value computed as described in Appendix C. The return of empty cars is assumed to occur over the same arcs that were in the fore-haul.

The functions* have been formulated for various terrain conditions (hilly or flat), number of tracks (single, double, or triple), and power used for trains. Since, in the eastern region and in the vast majority of cases, the power used for trains is about 1.7 hp/trailing ton, this value has been assumed for this study. The use of flat and hilly terrain by Bronzini (1979) may be viewed as equivalent to free speeds of 41 and 32 mph, respectively. Therefore, the tracks were categorized by free speed as follows:

- Single track, free speed ≧ 35 mph (STHFS)
- Double track, free speed ≧ 35 mph (DTHFS)
- Triple track, free speed ≧ 35 mph (TTHFS)
- Single track, free speed < 35 mph (STLFS)
- Double track, free speed < 35 mph (DTLFS)

*Bronzini (1979) presented the actual Rail Link Travel Time Function in the report Transportation Flow Analysis-National Energy Transportation Study, Volume III, Technical Supplement (Network Model Documentation), Final Report, January, 1980, pp. 32-34, for the eastern region.

These functions are presented in Table 3.2.

Table 3.2. Arc Travel Time Functions

Condition	Flow Volume $0 \leq f_a \leq 0.95F$	Flow Volume $0.95F \leq f_a \leq F$
STHS	$[0.0243 + \frac{0.06f_a}{6.6284 - f_a}]\ l_a$	$[-2.1417 + 0.3621f_a]\ l_a$
DTHFS	$[0.0243 + \frac{0.006f_a}{19.9603 - f_a}]\ l_a$	$[-2.1417 + 0.12104f_a]\ l_a$
TTHFS	$[0.0243 + \frac{0.006f_a}{33.009 - f_a}]\ l_a$	$[-2.1417 + 0.07271f_a]\ l_a$
STLFS	$[0.0309 + \frac{0.0113f_a}{5.9861 - f_a}]\ l_a$	$[-4.0441 + 0.7551f_a]\ l_a$
DTLFS	$[0.0309 + \frac{0.0113f_a}{17.935 - f_a}]\ l_a$	$[-4.0441 + 0.252f_a]\ l_a$

3.3.1.2 Value of Time

In this study, different values of time in terms of dollars for carriers and shippers have been presented, as both have different perceptions of time.

3.3.1.3 Value of Time for Carriers

A carefully derived value of time for the carrier has not been reported in the literature. In absence of any such value, it has been modeled as the loss of revenue per hour of delay.

These factors have been calculated from the data reported by the Association of American Railroads (1980) for the year 1979.

To compute loss of revenue per hour of delay, revenue in dollars per train-hour of operation, for the eastern region is calculated as follows:

- Net ton-mile per train-hour (a statistic reflecting both the number of tons hauled and miles traveled during an average hour of a freight train operation); the eastern district equaled 24,573 ton-miles/train-hour in 1979.
- Average revenue per ton on Class I railroads in the eastern district equaled $16.53/ton.
- Average haul in miles per ton on Class I railroads in the eastern district equaled 595 mi/ton.

Thus, the value of a train-hour in ton-dollars is equal to (24,573 × 16.53 × 1/595) = 682.67511 ton-$/train-hour. This value must be converted to $/hour-ton, dividing it by the number of cars per train and the average tons of freight per carload:

- The number of cars per average freight train for eastern district was 67.7 cars/freight train in 1979.
- The average weight of a carload of freight for eastern district was 60 tons/car.

Thus, the value of loss of revenue per hour of delay is

$$\text{Loss of revenue per hour of delay} = \frac{682.67511}{67.7 \times 60} = 0.1680638 \text{ \$/hr-ton.}$$

3.3.1.4 Value of Time for Shippers

No value of time was assumed for shippers of coal in the present version of the model. The value of time for transportation of noncoal commodities was taken from Roberts and Dewees (1971). Their work is based on an inventory theory for evaluating the cost of time for freight. The cost of time components given by Roberts and Dewees for general freight are:

Travel time (t_t) = 0.362 \$/hour-ton

Waiting time (t_w) = 0.514 \$/hour-ton.

Reebie Associates (1972) found that the average railcar actually moves trains for only 16% of its time. The remaining 84% is spent waiting in yards and at loading and unloading facilities. Thus, the value of time for noncoal commodities for shippers is $(0.16 \times 0.362 + 0.84 \times 0.514) = 0.48968$ \$/hour-ton.

3.3.1.5 Operating Cost

The model chosen to calculate operating cost is the one used by the Interstate Commerce Commission (ICC). This model was chosen primarily because of its simplicity and extensive practical use by railroads. It does not consider track conditions other than length of haul. The cost basically is a function of haul length and flow volume. It has been derived by ICC over the years, based on regression analyses done separately for seven railroad regions. The ICC model includes both line haul and yard operating costs. For this study, line haul and yard operating costs were separated. The ICC model also differentiates on the basis of the commodity shipped and the type of car used. For the purpose of this study, this has been combined to two modes, one for coal and one, an aggregate model, for noncoal commodities. The latest version of the ICC model is based on 1977 costs.

The ICC model is limited in that it includes the use of the same variability ratios for all commodities and does not account for deferral of maintenance cost by the railroads. Variability ratios reflect average utilization of capacity. These have been chosen by the ICC as an aggregate number for all car loadings and commodities. They are in reality quite different. Since deferment of maintenance costs include the upgrading cost for track and way, they would be expected to influence operating costs. However, no account is made of this influence in the ICC methodology.

For transportation of coal an open hopper car is used that averages a capacity of 83.5 tons per car. The Rail Form-A cost function (detailed in Appendix D) yields the following for coal:

$$C_c = 3.191 + 1.5401641(l_a) \, , \tag{3}$$

where C_c = cost of transportation of coal by rail per ton, and

l_a = length of haul in miles on arc "a".

For noncoal commodities, the cost function is a weighted average of the cost functions for various commodities shipped in different types of cars. The weighting factor was determined by the number of cars of each type, and the average capacity of each type of car. The various types of cars taken into consideration are:

Box general equipped	(174,000 cars; 31.8 tons)
Box general plain	(321,500 cars; 31.8 tons)
Gondola general	(186,000 cars; 67.2 tons)
Livestock	(4,400 cars; 54.2 tons)
Flat general	(141,000 cars; 53.3 tons)
Refrigeration	(101,000 cars; 35.0 tons)
Tank 28K	(171,000 cars; 62.5 tons)

These have been obtained from Armstrong (1979, Chapter 9) and the Interstate Commerce Commission (1975).

The cost function for noncoal commodities thus derived is

$$C_{nc} = 18.561 + 2.363624(l_a) \, ,$$

where c_{nc} = cost of transportation of noncoal commodities by rail in cents per ton, and

l_a = length of haul in miles on arc "c".

The detailed derivation of this cost function is given in Appendix D.

3.3.2 Transshipment Cost Function

The transshipment cost function has been used to find the cost of transshipment of commodities between rail and water modes. Transshipment between rail and water consists of both dumping costs and delay costs.

3.3.2.1 Dumping Cost

The nominal cost of transshipment is a fixed dumping charge per ton for use of a facility. Since there are finite transshipment facilities, this has been modeled as

$$C_t = A\,\frac{c - 0.99f}{c - f} \qquad 0 \leqq f \leqq 0.99c \tag{5}$$

and

$$c_t = a + bf \qquad 0.99c \leqq f\ , \tag{6}$$

where c_t = dumping cost of transshipment in cents per ton,

a = fixed dumping cost in cents per ton,

c = capacity of the transshipment node,

f = flow at the transshipment node,

a = intercept of slope of Equation 5 at $f = 0.99c$, and

b = slope of Equation 5 for $f = 0.99c$.

It is assumed that dumping cost is independent of flow, but the flow must never exceed the capacity of the mode. To keep the flow below capacity, c, the cost, C_T, is made extremely high for flows greater than 0.99c. Equations 5 and 6 are represented in Figure 3.6. This approach has been used to obviate the need for adding a constraining equation to the model to represent capacity explicitly. Rather, at flows of coal less than 0.99% of capacity, the value of C_T in Equation 5 is very close to the dumping charge, A. The cost is not permitted to go to infinity at flows greater than 0.99c. Rather, a second steeply sloped linear function is used to compute cost. The slope, b, of Equation 6, for purposes of continuity is set equal to the slope (i.e., first derivative) of Equation 5 at 0.99c. Therefore "b" is equal to 10A/C. The intercept, a, equals -8.8A. The values for A and c are provided in the network data base for each transshipment link. The value for f is computed in the network solution. Any transshipment node that exceeds its theoretical capacity is noted in the solution.

3.3.2.2 Delay Cost

At any transshipment node as the traffic approaches capacity, congestion increases. With increases in congestion, the time needed for transshipment also rises rapidly, which implies that transshipment time is a function of flow. An approximate delay cost function for transshipment was developed and is given in Equations 7 and 8 below:

$$C_{TT} = A_T\left(\frac{c - 0.5f}{c - f}\right) \qquad 0 \leqq f \leqq 0.95c \tag{7}$$

and

$$C_{TT} = a_1 + b_1 f \qquad 0.95c \leqq f\ , \tag{8}$$

where C_{TT} = delay cost of transshipment in cents per ton,

A_T = fixed cost in cents per unit time of delay,

c = capacity of the transshipment node,

f = flow at the transshipment node,

a_1 = intercept of slope of Equation 7 at $f = 0.95c$, and

b_1 = slope of Equation 7 for $f = 0.95c$.

The above function has been based on the assumption that as flow increases the delay increases rapidly as capacity is approached. The slope of delay cost function is depicted in Figure 3.7. In a manner similar to dumping cost, the values of a, and b, were computed to be $-9.55A_T$ and $200A_T/c$, respectively.

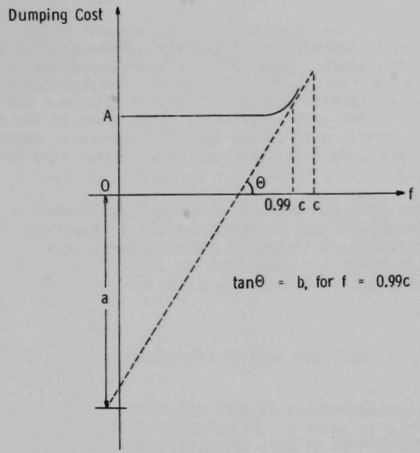

Fig. 3.6. Shape of the Transshipment Dumping Cost Function

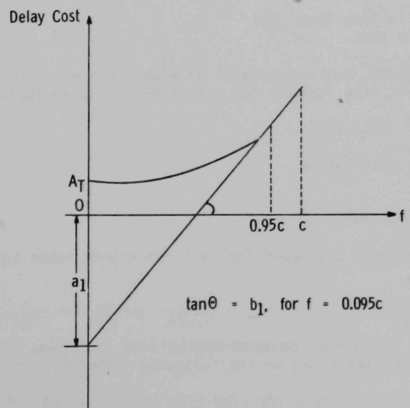

Fig. 3.7. Shape of the Transshipment Delay Cost Function

For a value of f approximately zero, which defines a free flow condition, there is some delay which is characteristic of the transshipment node. The parameter "0.5" in Equation 7 is an arbitrary value to represent the assumption that even for low traffic volumes delays will occur. The primary time spent in port (the time for loading) is computed as delay time on the water link. For f approaching capacity flow, the delay increases rapidly along the linear path described in Equation 8.

3.3.3 Water Delay Functions

Water links are characterized by three types of vessels. These vessels exhibit differing operating characteristics and load sizes. Delay functions are computed on the basis of speed, distance, size and coal dumping rate at the origin port. The time to unload the vessel is not counted for water as it is not counted for rail. Data for distance and coal dumping rate are given in the network data base for each water link. Also given in the network data base is a figure for maximum allowable draft based on the lesser of the water depths at either the origin or the destination of the link. This is used to compute vessel size for ocean tug-barge systems.

Integrated tug-barges/colliers and intracoastal waterway barge-towboat systems are assumed to be of a specific expected size--24,000 and 75,000 deadweight (long) tons, respectively. They are assumed to have open water speeds of 17 and 10 knots, respectively. The delay formulas for these two vessel types are as below:

For intracoastal waterway:

$$T = M/10 + 8250/D \ .$$

For ITB/Collier:

$$T = M/17 + 26400/D \ ,$$

where T = trip time-one way (hours),
M = distance (nautical miles), and
D = dumping rate of loading ports (short ton/hr).

Ocean tug-barge systems were not restricted to only certain allowed routes. Therefore, they must be allowed to vary in size to fit the circumstance of each port pair they are to serve. A formula was developed from statistics published in various waterborne trade periodicals to relate barge size to draft limitations. No such formula can be exact since much flexibility exists in the design of barges to meet various restrictions in dimension. However, given the representative nature of the statistics obtained, the following formula was estimated:

$$C = 1151 \cdot F - 9221 \ , \tag{10}$$

where C = capacity of load in long tons, and
F = draft of vessel in feet.

By substituting Equation 10 for load capacity in an equation similar to those given above at an open water speed of 10 knots, the formula for trip time for ocean tug-barges may be obtained:

$$T = M/10 + (1151 \cdot F - 9221)/1.1D \ ,$$

where T, M, D, and F are as given above.

3.4 TRANSPORTATION RATE FUNCTIONS

Equations based on distance were developed for rail train-load rates and for each of the three water vessel systems.

3.4.1 Rail Rates

Railroad rates for coal in trainloads or unit trains from each zone originating coal to each destination for coal were computed based on the following formula:

$$R = 2.62 + 0.02M \ ,$$

where R = rate in dollars per ton, and
M = route mileage.

This formula was obtained from the U.S. Department of Energy, Energy Information Administration, Office of Mid-range Analysis. It is used to compute railroad rates for USDOE's Mid-range Energy Forecasting System Model and was developed from actual rate and distance data by Data Resources, Inc., in 1977. The 1977 formula was increased by 51.3% to reflect rate increases on coal from mid 1977 (ExParte 343) to September, 1980 (ExParte 375).

3.4.2 Water Rates

Distance based formulas for water transportation rates were developed from analyses of the costs of operating different vessel types. Operating costs are very similar for ocean tug-barge and for intracoastal waterway barge-towboat systems. ITB/collier costs were computed from separate data and assumptions. These are outlined separately below.

3.4.2.1 Ocean Tug-barge

In estimating the cost of operating an ocean going tug-barge vessel of a size determined by the network parameters (e.g., channel depth), the cost of operating the vessel is divided into three interrelated components: barge costs, tug hire rates, and fuel costs. The tug hire rate includes all capital, insurance, and crew costs associated with the tugboat plus any corporate overhead and profit. Even if a utility were to own or lease its tugs, its costs would be similar. A survey of eleven major East Coast tug operations was made to determine the tug size and daily hire rates. These were normalized to cost per horsepower per day and plotted (Fig. 3.8). An indicative line was drawn through the plot which corresponds to the formula

$$R = 194.96 - 0.0158H ,$$

where R = hire rate in dollars per horsepower per 24-hour day, and
H = tugboat horsepower.

The size of the tug to be used on any particular link is related to the size barge in deadweight (long) tons (DWT), which is determined by Equation 10. A value of 0.275 is assumed to characterize the ratio of required tug horsepower to barge size in DWT. Daily tug costs are divided by 24 to compute hourly costs.

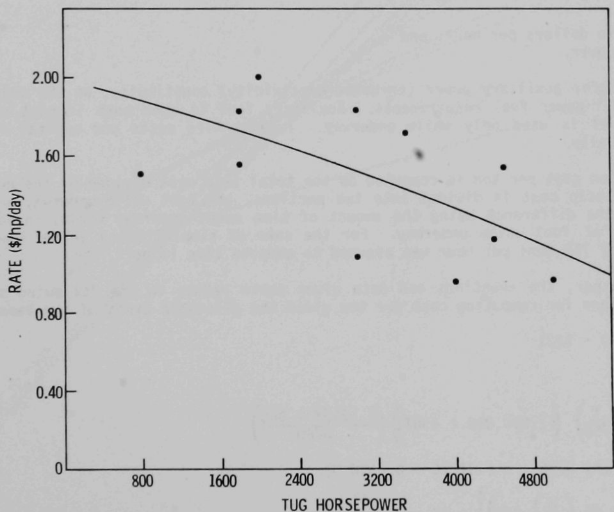

Fig. 3.8. Daily (24-hr) Hire Rate for Tugboat Service. From Transportation and Economic Research Associates, Inc., Survey of Selected East Coast Tug Operators.

Barge costs, on the other hand, are computed with the implicit assumption that the utility would own or lease the barge. In this case no allowance for the costs of corporate oversight or profit is considered. The size of the barge is determined from Equation 10. Based on costs of vessels reported in various water transport trade periodicals and on unpublished U.S. Maritime Administration statistics, the initial cost of the barge is estimated by the following formula:

$$C = 1{,}000{,}000 + 450S \quad ,$$

where C = cost in dollars, and
S = vessel size in deadweight tons.

The total dollar value of the barge is amortized in equal payments over 20 years when lease financed, at 11% interest rate, in equal annual payments of 12.558% of the principal. Annual costs for insurance and maintenance are also stated as factors of the initial cost of the barge. Maintenance cost is assumed to equal 5% (i.e., 1/20) of the cost of the barge, based on full "replacement" over the 20-year life of the barge. Insurance costs are assumed to be 1.5% of the cost of the vessel per year. These together constitute the annual costs of the barge. Annual cost is divided by 8760 to compute hourly costs.

Finally, the cost of fuel must be computed based on the horsepower. Typically some reserve horsepower is made available when matching a towboat to a barge. Consequently, operators try to maintain a maximum speed of 10 knots for safety in ocean tug-barge operations by operating at less than full throttle. Reasoning on the basis that the full horsepower requirement for control of the vessel is related to mass (i.e., total weight) of the vessel while the horsepower requirements to maintain reasonable speed are related, due to friction resistance, to the surface area of the vessel, fuel is computed as a fraction of total horsepower equal to the ratio of surface area to total volume of the vessel. In general the surface area of a solid is related to its volume to the two-thirds power. At $1.00 per gallon for marine diesel fuel, 0.06 gallons per horsepower per hour (assumes 30% efficiency and 140,000 Btu's per gallon), and a minimum full power requirement for tugboats of 630 horsepower (lowest expected in the trade), the cost per hour of running the vessel at sea is given by the following formula:

$$C = 0.06 \left(\frac{H^{2/3}}{630}\right) 630 \quad ,$$

where C = cost in dollars per hour, and
H = horsepower.

The use of fuel for auxiliary power (on-board electricity) constitutes, on the average, 5% of the vessel's full power fuel requirements. Auxiliary fuel is used both in port and at sea, while vessel fuel is used only while underway. Tugboat hire costs and capital costs are incurred continually.

The transportation cost per ton is computed as the total trip cost divided by the number of tons delivered. The trip cost is divided into two portions, the cost while underway and the cost while in port--the difference being the amount of time spent underway versus in port and the additional cost of fuel while underway. For the sake of simplicity, a vessel loading and unloading rate of 750 tons per hour was assumed to compute time in port.

When taken together, the equations and data given above reduce to the following sequential system of equations for computing cost per ton given the allowable draft of the vessel:

$$T = 1151.5\ D - 9221$$

$$H = 0.275T$$

$$\begin{aligned} C = \Bigg[& \left(\frac{2M}{10} + \frac{T}{750}\right) \left((1{,}000{,}000 + 450T)\right) \left(\frac{0.12558 + 065}{8760}\right) \\ & + 0.05\ (H)\ 0.06 + H\ (194.96 - 0.0158\ H) \\ & + \frac{2M}{10} \left(0.06 \left(\frac{H}{630}\right) 630\right)\Bigg] / 1.1T \quad , \end{aligned}$$

where M = distance between ports in nautical miles,
T = deadweight tonnage = vessel size = load in long tons,
D = vessel draft in feet,
H = tug-boat horsepower, and
C = cost of transportation in dollars per short ton.

Substituting different allowable vessel drafts into the system of equations yields linear cost functions as shown in Figure 3.9 when only distance is varied. As shown in the figure, the maximum-sized vessel exhibits expected economies of scale only at and beyond some threshold distance, with the exception that at vessel drafts greater than 20 feet the threshold distance decreases rather than increases as it does for drafts between 10 and 20 feet. Therefore, for computational simplicity, a curve was used to choose the best cost (i.e., vessel size for the distance traveled) for allowable drafts up to 20 feet. Since no link has an allowable draft greater than 35 feet, three linear equations for vessels of 30, 33, and 35 feet were used to approximate trip costs at distances greater than their respective threshold distances. The water transport rate decision algorithm with cost equations for ocean tug-barge is given in Figure 3.10. As the flow chart in the figure indicates, at draft limits less than 20 feet, or at distances less than the threshold distances of 275,255 or 250 miles, as appropriate to their respective draft limits, the optimal barge/tugboat size is characterized by equation (1) in the figure. If the allowable draft (i.e., the depth of the port) is greater than 20 feet, then tests are made to determine if it is greater than 30 or 33 feet. For drafts between 20 and 30 feet the distance on the link must be greater than 275 nautical miles to use Equation 2; otherwise Equation 1 is used. The remainder of the diagram is interpreted in a similar fashion.

3.4.2.2 Intracoastal Waterway Barge-Towboat

Cost calculations for intracoastal waterway barge-towboat systems are similar to ocean tug-barge systems but made very much simpler by the assumption that barge and load size are fixed rather than variable. Therefore, the final form of the cost function is a single linear equation in distance. The equation is:

$$C = 0.781 + 0079M ,$$

where C = transportation cost in dollars per short ton, and
M = distance in nautical miles.

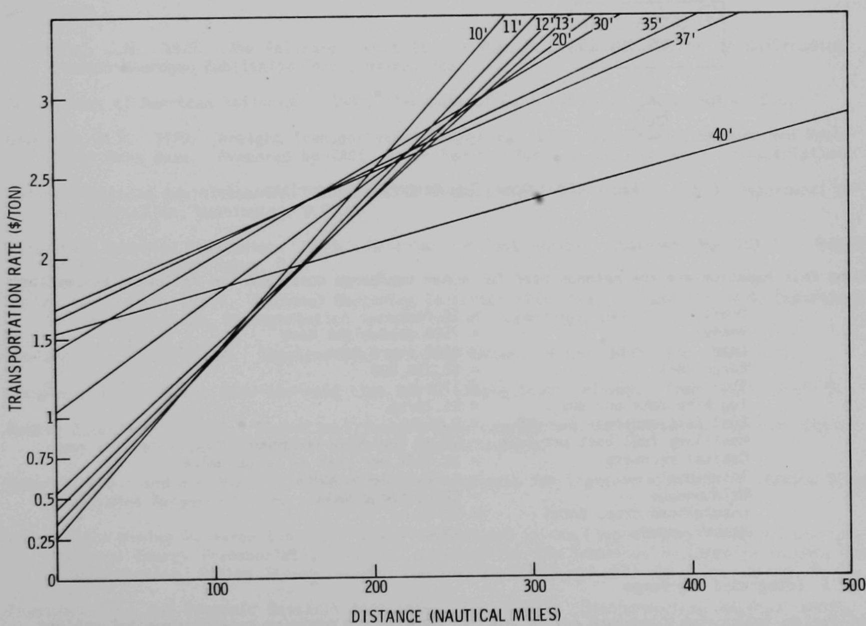

Fig. 3.9. Ocean Tug-Barge Rate Functions by Allowable Vessel Draft

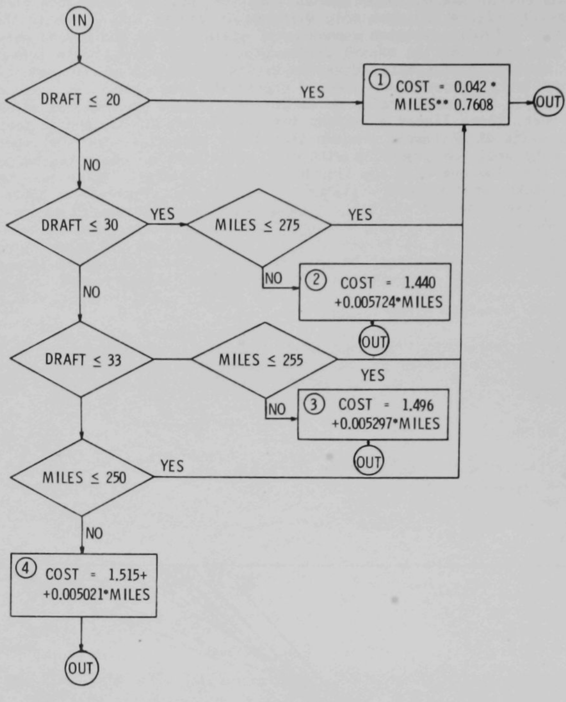

Fig. 3.10. Ocean Tug Barge Rate Algorithm

Behind this equation are the methods used for ocean tug/barge costs and the following assumptions:

Draft	= 10 feet
Vessel	= 7500 deadweight tons
Load	= 8250 short tons
Barge cost	= $2,230,000
Tug	= 1700 hp
Tug hire rate per day	= $1.70/hp
Fuel cost underway per day	= 0.06/hp
Auxiliary fuel cost per hour	= 5% of fuel cost underway
Capital recovery	= 12.558% per year on barge value
Insurance	= 1.5% of barge value
Maintenance	= 5% of barge value
Load/unload time, total	= 30 hours
Vessel speed	= 10 knots

3.4.2.3 Integrated Tug-Barge

Cost for an integrated tug-barge may be used to approximate costs on a self-propelled collier. A self-unloading vessel is examined in this case. Self-unloaders are capable of being unloaded much faster than shoreside unloading. They do not require as much shoreside space, which is in many cases in short supply and they are more flexible.

Although the basic approach to cost estimating is the same as for other vessel types, crew costs must be dealt with explicitly. These were taken from a 1978 Maritime Administration study as compiled for a 25000 deadweight ton tanker (U.S. Department of Commerce 1978, p. 7). Daily crew costs for a crew of 25 plus other operating expenses, (subsistence; stores, supplies and equipment; maintenance and repair; insurance; and other) was escalated to 1980 to derive an estimate of $7500 per 24-hour period.

The vessel is assumed to have an initial cost of 46.3 million dollars based on a review of various vessels financed through U.S. Maritime Administration programs. Assuming leased financing at 11% annual payback is 12.558% of the principal amount per year, which equals $15,930 per day.

Fuel is required for propulsion, electrical power aboard ship and for operating the self-unloading equipment. The vessels 10,000 horsepower main engines would consume fuel at the rate of 0.37 per horsepower per hour. To maintain the 15-knot speeds that characterize these vessels, they operate at full throttle at sea. Given a price per gallon of one dollar and a weight of 7.2 pounds, the hourly cost of fuel for propulsion would be $511. Auxiliary fuel is about 5% and fuel for self-unloading about 33% of propulsion fuel, which results in hourly auxiliary and self-unloading fuel cost of $26 and $170, respectively.

These costs are allocated over a trip cycle determined by distance, an assumed loading and unloading rate of 2500 tons per hour and a speed of 15 knots. The final form of the cost equation in only the distance variable is:

$$C = 0.906 + 0.0074M \ ,$$

where C = transportation cost in dollars per short ton, and
M = distance in nautical miles.

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4. SOFTWARE LOGIC

4.1 FREIGHT NETWORK EQUILIBRIUM MODEL

As indicated in Section 2, the Freight Network Equilibrium Model (FNEM) uses an iterative solution technique known as the Frank-Wolfe Algorithm. An overview of this algorithm as it was applied in this study is presented in this section.

Detailed information on the FNEM for the systems professional is to be issued as a part of a user's manual.

The FNEM was utilized for the FUA impact analysis; that version of the model can be run in one of two operating modes: preloading or coal-loading. FNEM is designed to treat up to 15 commodities in both the preloading and main (coal) loading phases, if appropriate input data are supplied. For the FUA impact analysis the preloading mode, a single commodity (non-coal freight), is loaded onto the network. In the coal-loading mode, which uses the results of the preloading phase as the initial network loading, six different types of coal are dealt with simultaneously. Since the program logic for both modes of operation is essentially the same, most of the subroutines are used in both modes of operation. The only differences in program logic appear in the separate main program and in an additional pair of control subroutines (SPRLOD, PRELOD) for the preloading phase. A listing of all the subroutines, with a brief description of what they do is given in Table 4.1. The interrelationships of primary subroutines for the preloading phase is given in Figure 4.1, and for the coal-loading phase in Figure 4.2. The numbers beside the arrows indicate the order in which the subroutines are called. Since the algorithm is an iterative one, some subroutines (or sets of subroutines) will be used repeatedly until some preset stopping criterion has been reached. As can be seen in Figures 4.1 and 4.2, the two cost routines (SCOST and CCOST) need to be called repeatedly as part of the line search routine (BSRCH). In addition, the set of subroutines that comprise the iterative portion of the algorithm (OKA, BSRCH, SCOST, LPATH, SHPATH, UPDATE) need to be used in each iteration.

The FNEM programs detailed in Figures 4.1 and 4.2 were run on a small test network to illustrate their use. This test network is explained in Section 5.

4.2 DISAGGREGATION MODEL

4.2.1 Coal Production

The data flow associated with the coal production disagrregation methodoloogy is shown in Figure 4.3. The three basic data sets used as inputs to the model are COUNTY.COAL78, FNEM.DATA (NE78FLOW), and FNEM.DATA(DRISUPP).

COUNTY.COAL78 contains the basic historical information about coal production in the Northern and Southern Appalachian regions. Each record of this data set consists of the following elements.

- County FIPS code
- Bureau of Mines coal production region code
- 1978 production level (10^3 ton)
- 1977 production level
- 1976 production level
- 1975 production level
- Average sulfur content (%)
- Btu/lb
- Reserves (10^6 ton)

These data have been entered and stored in free format on COUNTY.COAL78. FNEM.DATA(NE78FLOW) is a short data set used to estimate the percentage of each county's production which is destined for the Northeast in the forecast scenarios. Each record has three fields:

- Bureau of the Mines Production Region Number
- Total BOM region production (1978)
- BOM production destined for Northeast states (1978)

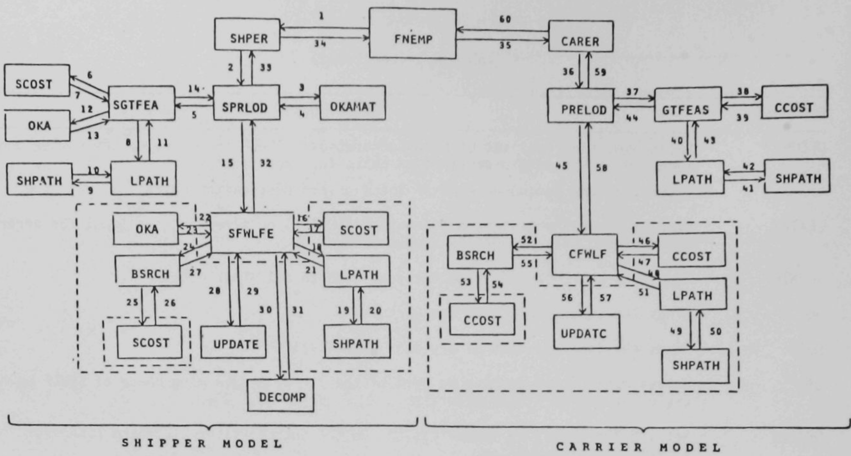
Table 4.1. FNEM Subroutines

Subroutine	Function(s)
FNEMP	- Main program for preloading phase. - Dimensions all arrays. - Reads in input data. - Echo prints all input data. - Calls subroutine SHPER to initiate use of the shipper model. - Converts shipper model output to appropriate format for use by carrier model. - Calls subroutine CARER for each carrier to initiate use of the carrier model. - Prints final solution file.
FNEMC	- Main program for coal-loading phase. -Same functions as FNEMP -
SHPER	- Controls the operation of the shipper model by properly sequencing the use of the shipper subroutines for either mode of operation.
SPRLOD	- Controls the operation of the preloading of the shipper model by setting and checking variables unique to the preloading problem.
SGTFEA	- Finds an initial feasible solution for the shipper problem based on zero (or preloaded) flows.
SFWLF	- Finds successively better solutions to the shipper problem at each iteration by calling subroutines that perform the linear programming (OKA, LPATH) and line search (BSRCH) phases of the Frank-Wolfe algorithm. - Determines the stopping criterion. - Calls the subroutine to decompose path flows. - Prints iteration log, link loadings, arc costs, demand variables, carrier demands, and path flows.
ICLEAR	- Clears an Integer * 2 array.
KLEAR	- Clears an Integer * 4 array.
COPY 1	- Copies a one-dimensional array to one with another name.
CARER	- Controls the operation of the carrier model by properly sequencing the use of the carrier subroutines for either mode of operation.
PRELOD	- Controls the operation of the preloading phase of the carrier model by setting and checking variables unique to the preloading problem.
GTFEAS	- Finds an initial feasible solution for the carrier problem based on zero (or preloaded) flows.
CFWLF	- Finds successively better solutions to the carrier problem at each iteration by calling subroutines that perform the linear programming (LPATH) and line search (BSRCH) phases of the Frank-Wolfe algorithm. - Determines the stopping criterion. - Prints carrier identity, iteration log, link loadings, arc costs, and path flows.
UPDATE	-Updates the listing and flow values for all paths generated in SFWLF.

Table 4.1 (concluded)

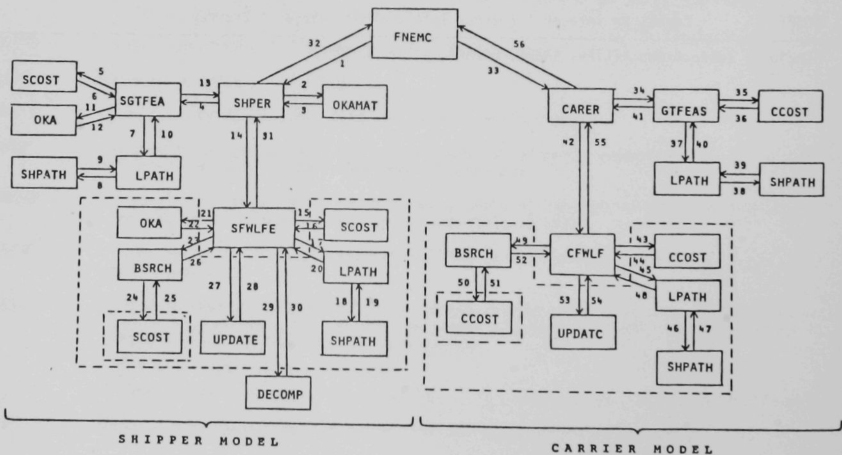
Subroutine	Function(s)
DECOMP	- Decomposes the final set of paths generated in SFWLF to determine the number and identity of the origin-destination pairs for each carrier. - Determines the demand on each of these origin-destination pairs.
LPATH	- Regulates the shortest path subroutine (SHPATH) by screening the input for errors and defining the appropriate output arrays.
SHPATH	- Finds the shortest path from the root node to all other nodes.
DOT	- Finds the inner product of two vectors.
DOT1	- Finds the inner product of a vector with itself.
OKA*	- Solves a Hitchcock problem as part of the linear programming phase of SFWLF by use of an out-of-kilter algorithm.
OKAMAT	- Sets up the necessary parameters to run the out-of-kilter algorithm (OKA) for either mode of operation.
BSRCH	- Performs the line search phase of SFWLF and CFWLF by the use of a binary search method.
CCOST	- Calculates the cost of travel to the carrier for each arc as a function of flow and arc attributes.
SCOST	- Calculates the cost of travel to the shipper for each arc as a function of flow and arc attributes.
UPDATC	- Updates the listing and flow values for all paths generated in CFWLF.
ICOPY1	- Copies an integer * 2 array into another integer * 2 array.

*Includes subroutines KILTER, LABEL, BREAKT, RAISE, CUTOFF.



NOTE: Subroutines contained within dashed lines are repeatedly called.

Fig. 4.1. Primary Subroutines in the Preloading Phase



NOTE: Subroutines contained within dashed lines are repeatedly called.

Fig. 4.2. Primary Subroutines in the Coal-Loading Phase

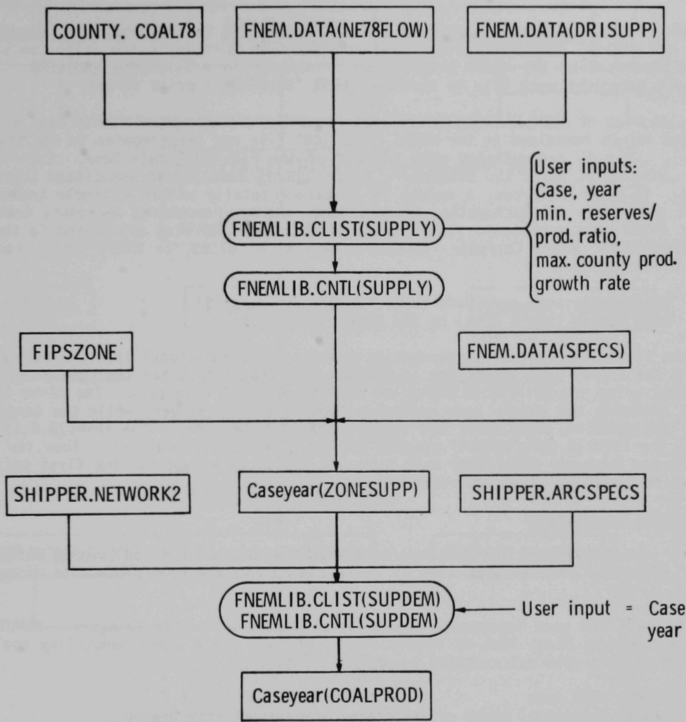


Fig. 4.3. Coal Production Disaggregation Data Flow and Software Logic

FNEM.DATA(DRISUPP) contains supply data for each of the seven basic scenarios (see Sec. 2, Table 2.1). For a given line, the elements recorded are:

- Case name
- Year
- Coal supply (10^6 ton) in six sulfur classes

FNEMLIB.CLIST(SUPPLY) is a WYLBUR macro language program which is used to get user inputs and set up and run the supply disaggregation program FNEMLIB.CNTL(SUPPLY). User inputs requested include the case (Base, NSPS, or Oil SIP), year (1978, 1985, or 1991), the maximum allowable annual production rate increase, and the minimum allowable reserves to production ratio. With these inputs, FNEMLIB.CLIST(SUPPLY) sets up the JCL in the FNEMLIB.CNTL(SUPPLY) program and runs it from WYLBUR.

FNEMLIB.CNTL(SUPPLY) consists of three separate job steps that set up input in standard form, run a linear program to perform disaggregation, and reformat output to render it suitable for further processing. The core program of this series is MINOS (Murtaugh and Saunders 1977), developed at Stanford University to perform nonlinear and linear optimization (only the linear option is used for disaggregation). MINOS input and output formats are essentially the same as those of IBM's MPSX system (IBM 1972); only minor modifications are required to assure compatibility.

The first step of FNEMLIB.CNTL(SUPPLY) sets up input in standard format for use by MINOS. Three input files, COUNTY.COAL78, FNEM.DATA(NE78FLOW), and FNEM.DATA(DRISUPP), are processed to define the constraint matrix (see Sec. 2.2.1). The constraint matrix is specified in standard MPS format and written on a (temporary) single output file (corresponding to the MINOS "MPS" file or the MPSX "CONVERT DATA" file).

The second job step reads two input files. FNEM.DATA(SPECS) (corresponding to the MINOS "SPECS" file) to set control parameter values, and the MPS file written in the prior job step. The files are processed by the MINOS program, which resides in a file MINOSAUG.LOAD. Output is written on a temporary work file in standard (MPSX "SOLUTION") print format.

The last job step of FNEMLIB.CNTL(SUPPLY) retrieves the disaggregated county coal production by sulfur type values contained in the MINOS "SOLUTION" file and reaggregates to the transportation zone level. This is accomplished with the aid of the FIPSZONE* data base. Each record of FIPSZONE contains at least two elements: a FIPS county code and an associated transportation zone code. In most instances, a county is contained totally within a single transportation zone. In some cases (Massachusetts, Rhode Island, and New Hampshire) secondary transportation zones are added when necessary. The results of the final job step are stored in the data set Caseyear(ZONESUPP), where Caseyear represents BASE78, or OIL85, or NSP91, etc. Each record contains seven fields:

- Coal supply zone node code (e.g., 073D00 for zone 73)
- Coal supply (short tons) by six sulfur categories

This is the final step in the disaggregation process. One additional list processing is required to convert the supply node names such as 073D000 into proper form for the FNEM program: This is accomplished using the SHIPPER.NETWORK2 and SHIPPER.ARCSPECS data sets. The first of these two data sets contains the supply node names for each supply access arc, while the second data set contains corresponding line data, but using the FNEM node codes. The FNEMLIB.CLIST(SUPDEM) macro and the FNEMLIB.CNTL(SUPDEM) program perform this code conversion. Thus the Caseyear-(ZONESUPP) and Caseyear (COALPROD) data sets are identical except for the first entry on each record, which symbolizes the zone represented.

4.2.2 Non-FUA Coal Demand

Figure 4.4 is a diagram of the software/data flow for the non-FUA coal demand disaggregation routine. After the initial step this is quite similar to the coal production disaggregation routine.

Three data sets are used to compute county level demand by sulfur category. NONUTIL.SHARE contains a state by state list of county shares of 1975 state level nonutility coal demand. Each record of this data set contains two pieces of data:

- County FIPS code
- County fractional share of associated state nonutility demand

UTIL85.SHARE and UTIL91.SHARE are analogs of NONUTIL.SHARE for the utility sector. Rather than appointing historical state demand to each county in that state, however, projected coal-fired utility generating capactity is used. Thus, each record in these data sets contains:

- County FIPS code
- County fractional share of 1985 (1991) coal-fired generating capacity

Caseyear(DRIDEMD), which represents BASE78(DRIDEMD) and its six cousins (the other six cases), contains the DRI demand assumptions for each state (see Sec. 2, Tables 2.2 throught 2.8). Each record of these data sets contains:

- State code (first two digits in the FIPS code)**
- Coal demand (10^6 ton) in six sulfur categories
- FUA demand (10^6 ton)
- Non-FUA utility demand, percent of total non-FUA demand.

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*The FIPSZONE file, as currently constituted, contains transportation zone codes only for Northern Appalachia and immediately contiguous areas. In particular, it does not include zone codes for Southern Appalachia; consequently, although production figures for the Southern Appalachia BOM districts are contained in the COUNTY.COAL78 file, and although the Southern Appalachia production is disaggregated in the previous step of this process, Southern Appalachian disaggregation information is not at present passed on to the later stages of processing.

**There is one special case: the three New England states of Maine, New Hampshire, and Vermont are aggregated and given the code 99.

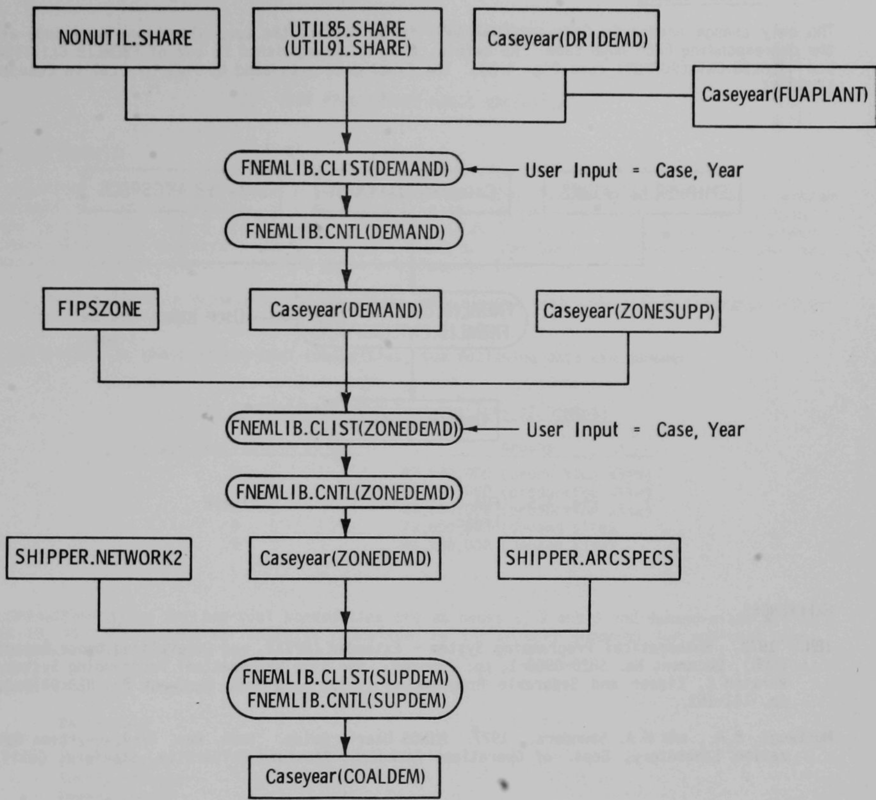

Fig. 4.4. Non-FUA Coal Demand Data Flow and Software Logic

Caseyear(FUAPLANT) is the coal tonnage by sulfur type assigned to each FUA plant, as illustrated in Table 2.10. Each record of these data sets contains:

- FUA plant zone node code (e.g., 038F011 for Bridgeport Harbor)
- State code (first two digits in the FIPS code)
- Coal demand (in tons) for each of the six sulfur types

FNEMLIB.CLIST(DEMAND) is a WYLBUR macro language program which prompts the user for a case and year, sets up the JCL in the FNEMLIB.CNTL(DEMAND) program for that case and runs it.

FNEMLIB.CNTL(DEMAND) first computes the total non-FUA coal in each DRI demand region by subtracting the state totals of Caseyear(FUAPLANT) from Caseyear(DRIDEMD). NONUTIL.SHARE and UTIL85.SHARE or UTIL91.SHARE are then used to apportion the non-FUA demand projections to the county level. The resulting forecasts are contained in Caseyear(DEMAND) for each of the seven scenarios.

Just as in the production disaggregation routine, these county level forecasts are aggregated to the transportation zone level using FIPSZONE data and the FNEMLIB.CLIST(ZONEDEMD) and FNEMLIB.CNTL (ZONEDEMD) programs. The resulting data sets are called Caseyear(ZONEDEMD).

The final step in this process is to convert the demand node names (for example, in the form 078D000 for zone 78) into the corresponding FNEM codes. After this is complete, the coal demand data is contained in the data sets Caseyear(COALDEM).

4.2.3 FUA Coal Demand

The only change needed in Caseyear(FUAPLANT) is to replace the powerplant zone node code with the corresponding FNEM node code. As before, this is accomplished by use of FNEMLIB.CLIST(SUPDEM) and FNEMLIB.CNTL(SUPDEM) (see Fig. 4.5). The final data sets used by FNEM are called Caseyear-(FUADEM).

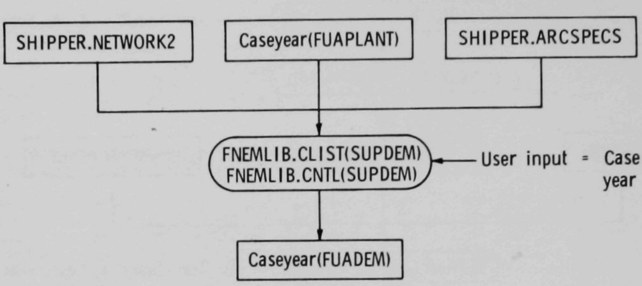

Fig. 4.5. FUA Coal Demand Flow and Software Logic

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5. TEST PROBLEM AND MODEL VALIDATION

5.1 TEST PROBLEM

The algorithm and software comprising the Freight Network Equilibrium Model (FNEM) may be better understood through application to a hypothetical test problem. In the test network chosen (shown in Fig. 5.1), there are 34 arcs, 15 nodes, and 20 O-D pairs. Nodes 8 and 9 are transshipment points for carriers 1 and 2 and modes A and B. The numbers in circles show the arc numbers in the above network. The O-D pairs are shown in Table 5.1.

For the test network, a maximum of 25 iterations were allowed with line search tolerance = 0.01 and Frank-Wolfe Tolerance = 2,000,000 tons.

For the preloading phase of non-coal commodities, the following data are assumed:

Zonal Production/Demand Amounts--Tons of Noncoal

Origin-Destination (O-D)	Amount
1	47,500,000 (production site)
2	40,000,000 (production site)
3	30,000,000 (production site)
4	75,000,000 (demand site)
5	42,500,000 (demand site)

The production sites for non-coal commodities are at nodes 1, 2 and 3 and demand sites are at nodes 14, 15. The demand variables as calculated by the shipper submodel for non-coal commodities are given in Table 5.2.

To input this data requires the use of 6 data files:

- Basic data
- O-D pairs
- Point array
- Supply amounts
- Demand amount
- Arc specifications

The point array and the arc specification files are the same for either preloading or coal-loading. The basic data file is also the same for both, except for the entry that signals the model as to whether it is preloading or coal-loading. The supply and demand amounts are different for each mode of operation. The format of each file is given in Table 5.3. The definition of entries is given in Table 5.4. The results are given in Tables 5.5 through 5.11. The activity log for the shippers' model, which should only be interpreted as interim results for any run of the model, is given in Table 5.5. The decomposition subroutine, which is the bridge between the shipper and carrier submodels, uses the demands given in Table 5.2 to produce the carrier-specific demands given in Table 5.6. These demands were then used as inputs to the carrier model. The carrier activity log, which is a synthesis of the results, for each carrier and which represents the final solution of the preloading case, is given in Table 5.7. Figure 5.2 is a map of the network indicating this final preload flow pattern. In all cases arcs not listed carry zero flow.

Using the flows given in Table 5.7 as "preloading," the multiple commodity coal case was run. The input amounts are given in Tables 5.8 and 5.9.

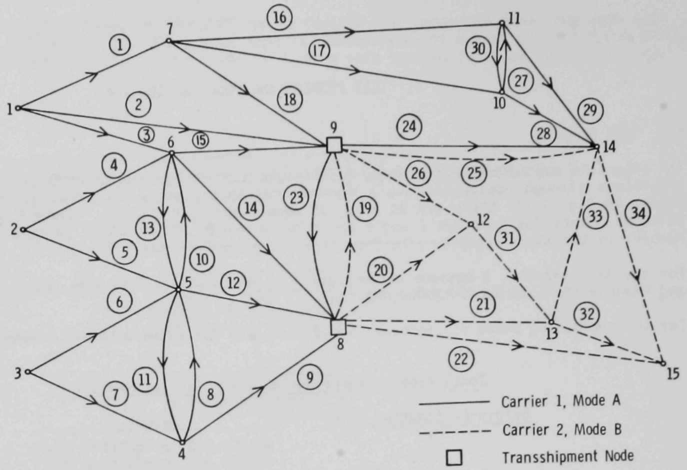

Fig. 5.1. Test Network

Table 5.1. O-D Pairs in the Test Problem

O-D Pair	Origin	Destination
1	1	2
2	1	3
3	1	14
4	1	15
5	2	1
6	2	3
7	2	14
8	2	15
9	3	1
10	3	2
11	3	14
12	3	15
13	14	1
14	14	2
15	14	3
16	14	15
17	15	2
18	15	2
19	15	3
20	15	14

Table 5.2. Non-Coal Demand by O-D Pair

O-D Pair	Origin	Destination	Amount (ton)
3	1	14	47,500,000
7	2	14	27,500,000
8	2	15	12,500,000
12	3	15	30,000,000

Demand on other O-D pairs is zero.

Table 5.3. Input Data Files

Input File	Input Record							
BASIC DATA	NSTATE	NCAR	IARCS	NODES	IODS	IXODS	MAXC1	MAXS
	MAXARC	MAXP	ICLTYP	IPZONE	ICLZON	IDMZON	NUMFUA	NEZONE
	IODSC1	IODSC2	IODSC3	IODSC4	IODSC5	EPSC		
	NETDES							
PRELOAD O-D PAIRS	NXROOT(1)	NXDES(1)						
	NXROOT(2)	NXDES(2)						
	NXROOT(3)	NXDEX(3)						
	.	.						
	NXROOT (IXODS)	NXDES (IXODS)						
COAL O-D PAIRS	NROOT(1)	NDES(1)						
	NROOT(2)	NDES(2)						
	NROOT(3)	NDES(3)						
	.	.						
	NROOT (IODS)	NDES (IODS)						
POINT ARRAY	POINT(1)							
	POINT(2)							
	.							
	POINT(NODES)							
PRELOAD SUPPLY	IPO(1)							
	IPO(2)							
	IPO(3)							
	.							
	IPO(IXODS)							
PRELOAD DEMAND	IPD(1)							
	IPD(2)							
	IPD(3)							
	.							
	IPD(IXODS)							
COAL SUPPLY	ICO(1,1)	ICO(2,1)	ICO(3,1)	ICO(4,1)	...	ICO(ICLTYP,1)		
	.					.		
	ICO(1,ICLZON)	.	.	.		ICO(ICLTYP,ICLZON)		
COAL ZONAL DEMAND	ICD(1,1)	ICD(2,1)	ICD(3,1)	ICD(4,1)	...	ICD(ICLTYP,1)		
	.					.		
	ICD(1,IDMZON)	.	.	.		ICD(ICLTYP,IDMZON)		
COAL FUA DEMAND	ICDFUA(1,1)	ICDFUA(2,1)		ICDFUA(3,1)	...	ICDFUA(ICLTYP,1)		
	.					.		
	ICDFUA(1,NUMFUA)	.		.	.	ICDFUA(ICLTYP,NUMFUA)		
ARSPECS	TO(1)	CAR(1)	ARCNAM(1)	IATTR1(1)	IATTR2(1)	IATTR3(1)	ICFCN(2)	ITWIN(1)
	TO(2)	CAR(2)	ARCNAM(2)	IATTR1(2)	IATTR2(2)	IATTR3(2)	ICFCN(2)	ITWIN(2)
	.							.
	TO(IARCS)	CAR (IARCS)	ARCNAM (IARCS)	IATTR1 (IARCS)	IATTR2 (IARCS)	IATTR3 (IARCS)	ICFCN (IARCS)	ITWIN (IARCS)

Table 5.4. Definition of Input Terminology

Term	Definition
NSTATE	Variable defining operational mode (4 = preloading, 5 = coal)
NCAR	Number of carriers
IARCS	Number of arcs
NODES	Number of nodes
IODES	Number of coal O-D pairs
IXODS	Number of preload O-D pairs
MAXC1	Maximum number of Frank-Wolfe iterations (carrier model)
MAXS	Maximum number of Frank-Wolfe iterations (shipper model)
MAXARC	Maximum number of arcs in a path
ICLTYP	Number of coal types
MAXP	ICLTYP X maximum number of paths
IPZONE	Number of preloading origins (or destinations)
ICLZON	Number of coal origins
IDMZON	Number of coal destinations
NUMFUA	Number of FUA powerplants
IODSC1	Maximum number of O-D pairs for carrier 1
IODSC2	Maximum number of O-D pairs for carrier 2
IODSC3	Maximum number of O-D pairs for carrier 3
IODSC4	Maximum number of O-D pairs for carrier 4
IODSC5	Maximum number of O-D pairs for carrier 5
EPSC	Frank-Wolfe tolerance
NETDES	Network description (alpha)
NXROOT (I)	Preloading origin of O-D pair I
NXDES (I)	Preloading destination of O-D pair I
NROOT (I)	Coal origin of O-D pair I
NDES (I)	Coal destination of O-D pair I
POINT (I)	First arc leaving node I
IPO (I)	Amount of preloading commodity produced at I
IPD (I)	Amount of preloading commodity demanded at I
ICO (I, J)	Amount of coal type I produced at J
ICD (I, J)	Amount of coal type I demanded at J
ICDFUA (I, J)	Amount of coal type I demanded at FUA plant J
TO (I)	B-node of arc I
CAR (I)	Carrier controlling arc I
IATTR1 (I)	First attribute of arc I
IATTR2 (I)	Second attribute of arc I
IATTR3 (I)	Third attribute of arc I
ICFCN (I)	Cost function used for arc I
ITWIN (I)	Return arc for arc I

Table 5.5. Activity Log for Shippers' Model for Non-Coal Commodities--Preloading Phase

Arc	Flow (ton)	Arc Cost for Non-Coal ($/ton)
3	47,500,000	0.04
4	27,500,000	0.05
5	12,500,000	0.05
6	30,000,000	0.06
12	42,500,000	0.05
15	75,000,000	0.07
22	42,500,000	0.15
24	75,000,000	0.13

Flow on all other arcs is zero.

Table 5.6. Carrier Demands

O-D Pair	Origin	Destination	Demand
		Demand--Carrier 1	
1	1	14	47,500,000
2	2	14	27,500,000
3	2	8	12,500,000
4	3	8	30,000,000
		Demand--Carrier 2	
1	8	15	42,500,000

Table 5.7. Activity Log for Carriers' Model for Non-Coal Commodities--Preloading Phase

Arc	Flow (ton)	Arc Cost for Non-Coal ($ton)	Carrier	Mode
1	6,431,920	0.0588188	1	A
2	34,609,700	0.163114	1	A
3	6,458,350	0.588380	1	A
4	27,500,000	0.0729190	1	A
5	12,500,000	0.0671802	1	A
6	26,277,800	0.132675	1	A
7	3,722,180	0.0954291	1	A
9	3,722,180	0.113992	1	A
12	38,777,800	0.0785597	1	A
15	33,958,300	0.106373	1	A
18	6,431,920	0.104459	1	A
19	1,660,160	0.105384	2	B
22	40,839,800	0.467812	2	B
24	75,000,000	0.215599	1	A
25	1,660,160	0.171250	2	B
34	1,660,160	0.186863	2	B

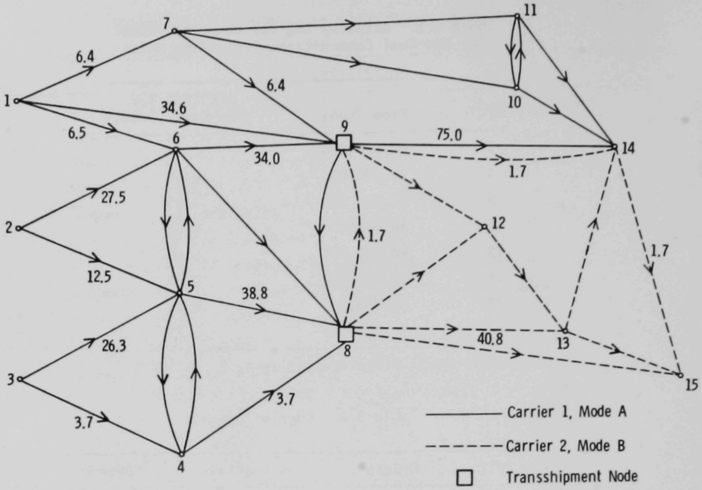

Fig. 5.2. Final Preload Test (10^6 ton)

Table 5.8. Zonal Production/Demand Amounts of Coal (ton)

Origin/ Destination	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Site
1	60,000,000	10,000,000	5,000,000	1,000,000	0	20,000,000	Production
2	15,000,000	20,000,000	2,500,000	0	10,000,000	0	Production
3	10,000,000	30,000,000	10,000,000	2,000,000	0	0	Production
4	30,000,000	15,000,000	7,500,000	1,500,000	10,000,000	0	Demand

Table 5.9. FUA Demand Amounts of Coal (ton)

FUA Plant	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
1	55,000,000	45,000,000	10,000,000	1,500,000	0	20,000,000

The coal production sites are at nodes 1, 2 and 3 and demand sites are at nodes 14 and 15. The FUA plant is located at node 15. The demand variables for coal as calculated by the shipper submodel are given in Table 5.10. As in the preloading case, these demands are used by the decomposition subroutine to produce carrier specific O-D pairs. These carrier specific demands are given in Table 5.11. The activity log for the coal-loading phase of the shippers' model, which should only be interpreted as interim results, is given in Table 5.12 and for the two carrier modes, the activity log is given in Table 5.13, along with the arc cost.

The final results of the test run are given in the two carrier activity logs (Table 5.13) and the network flow map (Figure 5.3). The carrier activity log indicates the flow of coal on each arc by coal type as well as the total preloaded flow. In addition the arc-costs corresponding to the final total flow on the arc is given in the last column. The flow map indicates only the total flow.

From the arc information available in this final activity log, issues such as total arc congestion, percent of congestion attributable to coal (by coal type if desired) and total arc costs can be analyzed by the user.

There are numerous optional reports for any application of FNEM; for the sake of brevity these are not described, but they include shipper and carrier paths, rank orderings of arcs according to congestion/seriousness of bottlenecks, and delivered prices of commodities. Some of these optional reports are used for the FUA impact analyses described in Section 6.

Table 5.10. Coal Demand by O-D Pair and Type

O-D Pair	Origin	Destination	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
3	1	14	30,000,000	10,000,000	5,000,000	1,000,000	0	0
4	1	15	30,000,000	0	0	0	0	20,000,000
7	2	14	0	5,000,000	2,500,000	0	10,000,000	0
8	2	15	15,000,000	15,000,000	0	0	0	0
11	3	14	0	0	0	500,000	0	0
12	3	15	10,000,000	30,000,000	10,000,000	1,500,000	0	0

Table 5.11. Coal Loadings by Carrier

O-D Pair	Origin	Destination	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
				Demand--Carrier 1				
1	1	14	30,000,000	10,000,000	5,000,000	1,000,000	0	0
2	1	8	30,000,000	0	0	0	0	20,000,000
3	2	14	0	5,000,000	2,500,000	0	10,000,000	0
4	2	8	15,000,000	15,000,000	0	0	0	0
5	3	8	10,000,000	30,000,000	10,000,000	2,000,000	0	0
6	9	14	0	0	0	500,000	0	0
				Demand--Carrier 2				
1	8	15	55,000,000	45,000,000	10,000,000	1,500,000	0	20,000,000
2	8	9	0	0	0	500,000	0	0

Table 5.12. Activity Log for Shippers' Model for Coal-Loading Phase

Arc	Coal (ton)						Preloading	Arc Cost for Coal ($/ton)
	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6		
3	60,000,000	10,000,000	5,000,000	1,000,000	0	20,000,000	6,458,350	0.04
4	0	5,000,000	2,500,000	0	10,000,000	0	27,500,000	0.05
5	15,000,000	15,000,000	0	0	0	0	12,500,000	0.05
6	10,000,000	30,000,000	10,000,000	2,000,000	0	0	26,277,800	0.06
12	25,000,000	45,000,000	10,000,000	2,000,000	0	0	38,777,800	0.05
14	30,000,000	0	0	0	0	20,000,000	0	0.09
15	30,000,000	15,000,000	7,500,000	1,000,000	10,000,000	0	33,958,300	0.07
19	0	0	0	500,000	0	0	1,660,160	0.08
22	55,000,000	45,000,000	10,000,000	1,500,000	0	20,000,000	40,839,800	0.150
24	30,000,000	15,000,000	7,500,000	1,500,000	10,000,000	0	75,000,000	0.130

Flow on other arcs is zero.

Table 5.13. Activity Log for Carriers' Model for Coal-Loading Phase

Arc	Coal (ton)						Preloading	Arc Cost for Coal ($/ton)
	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6		
				Carrier 1, Mode A				
1	6,824,122	2,274,709	1,137,353	227,471	0	0	6,431,920	0.0752950
2	23,175,850	7,725,290	3,862,644	772,529	0	0	34,609,700	0.157856
3	30,000,000	0	0	0	0	20,000,000	6,458,350	0.501533
4	3,648,005	8,648,005	2,500,000	0	10,000,000	0	27,500,000	0.0762392
5	11,351,990	11,351,990	0	0	0	0	12,500,000	0.0621810
6	5,097,337	15,292,000	5,097,337	1,019,467	0	0	26,277,800	0.7523
7	4,902,660	14,707,980	4,902,660	980,532	0	0	3,722,180	0.632634
8	1,126,098	3,378,295	1,126,098	225,220	0	0	0	0.052358
9	3,776,562	11,329,690	3,776,562	755,313	0	0	3,722,180	0.208994
10	2,432,004	7,296,011	2,432,004	486,401	0	0	0	0.0629098
12	15,143,420	22,726,250	3,791,431	758,286	0	0	38,777,800	0.123244
14	36,079,980	10,944,010	2,432,004	486,401	0	20,000,000	0	0.118151
15	0	5,000,000	2,500,000	0	10,000,000	0	33,958,300	0.105554
18	6,824,122	2,274,709	1,137,353	227,471	0	0	6,431,920	0.0836325
24	30,000,000	15,000,000	7,500,000	1,500,000	10,000,000	0	75,000,000	0.714081
				Carrier 2, Mode B				
19	18,761,900	15,350,650	3,411,254	1,011,688	0	6,822,509	1,660,160	0.716384
22	36,238,080	29,649,320	6,588,745	988,312	0	13,177,490	40,839,800	1.88075
25	18,761,900	15,350,650	3,411,254	511,688	0	6,822,509	1,660,160	1.08396
34	18,761,900	15,350,650	3,411,254	511,688	0	6,822,509	1,660,160	0.188246

Flow on other arcs is zero.

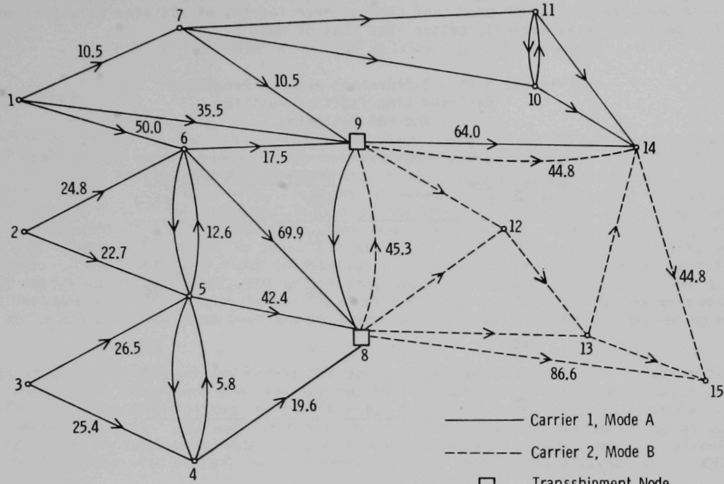

Fig. 5.3. Final Test Run, Coal Flows (10^6 ton)

5.2 MODEL VALIDATION

To ensure that the FNEM is a reliable forecasting tool, it must be shown to replicate historical freight system usage. This check was performed for the Northeast rail system for the base year 1978 and indicates that the accuracy of FNEM is considerably greater than previous predictive freight network models for the U.S.

The validation was performed using the version of FNEM described in Section 2.1 for a single aggregate freight commodity (i.e., there is only a single commodity index, r=1). The parameter $\gamma={}^1/\theta$ in the demand functions and the objective function of that version of the model (Equations 6 and 7, respectively, of Section 2.1) were approximated by comparison to the appropriate waybill statistics to ensure the demand for transportation used in the model was consistent with observed O-D pairings and O-D volumes. Knowledge of these demand-related parameters allowed FNEM to be run for the Northeast with 1978 commodity supplies (O_i) demands (D_j) and compared to FRA published density codes for <u>each</u> link of the Northeast rail network. The FRA density codes are a compact way of describing flow ranges for rail links; the coding scheme is described in Table 5.14. The only previous modeling effort to report a direct comparison with the FRA density codes is the Multimodal Network Model (MNM) (see Bronzini 1980). The MNM used an aggregate national version of the FRA network with 7 density codes; the codes used by MNM are the same as those given in Table 5.14 except that Code 6 corresponds to 30-40 million tons and Code 7 greater than 40 million tons.

Table 5.14. FRA Density Codes

Code	Annual Gross Tons (10^6)
1	0-1
2	1-5
3	5-10
4	10-20
5	20-30
6	>30

The cumulative frequency distribution of the differences between the 1978 FRA historical record and the computed density codes produced by FNEM and by MNM are exhibited in Table 5.15. As can be seen from these results, FNEM predicted nearly three-fourths of all arcs to within one density code. This performance is markedly better than that of MNM.

Table 5.15. Differences between Predicted Railroad Link Traffic Densities and FRA Estimates

Density Code Difference	Cumulative % of Links	
	MNM	FNEM
0	21	43
±1	55	74
±2	76	84
±3	90	92
±4	97	96
±5	99	100
±6	100	--

REFERENCES

Bronzini, M.S. 1980. Evoluation of a Multimodal Freight Transportation Network Model. Working paper, University of Tennessee. February.

6. APPLICATION OF FREIGHT NETWORK EQUILIBRIUM MODEL

6.1 INTRODUCTION

As discussed in Section 1, the Freight Network Equilibrium Model (FNEM) was used to predict the extent of railroad and port congestion due to increases in traffic attributable to FUA conversions in conjunction with other increases in traffic, as well as a detailed assessment of rail and water modal shares. This section is a summary of outputs of FNEM predicting coal movements under the Oil SIP within the Northeast Region of the United States. The data inputs are coal supplies and demands at the transportation zone level, obtained by disaggregating regional coal supplies and demands (discussed in Secs. 2.2 and 3.2); network data including rail, water, transhipment, supply and demand links (discussed in Sec. 3.1); and transportation cost functions, including operating costs, rates, and delays (discussed in Secs. 3.3 and 3.4). The summary analysis includes expected impacts to rail systems and ports associated with the movement of FUA coal as an incremental increase over the movement of all other commodities, including non-FUA coal.

The roles of both the shipper and carrier in route selection are considered in the model. For example, the shipper determines the coal source, the transportation mode (rail, water, or both), and the carrier. The model allows the rail carrier to optimize the route over its own system to minimize operating costs. The carrier's actions in the model are accounted for by allowing the routing to travel by both mainlines and branchlines of the rail system, but only allowing the shipment to interline with another rail carrier system if there is no alternative.

Four powerplants are not capable of receiving coal deliveries by water: Oswego in New York, and Mt. Tom and West Springfield, both in Massachusetts, and Cromby in Pennsylvania. Although Oswego is located on Lake Ontario, it is assumed that shipments of northern Appalachian coal will not be transported via the Great Lakes. The Mt. Tom and West Springfield powerplants are in western Massachusetts, where water deliveries are impossible. Cromby is located on the Schuylkill River, but the river is not navigable to the plant. These four powerplants must receive their coal shipments by rail. The remainder of the plants can receive coal by either rail or water, and mode selection is determined by delivered price by the shipper model.

The only assumption made regarding changes in the transportation system was an additional port on the eastern seaboard. For this analysis, it was assumed that a second or expansion port would exist in the New York-New Jersey area, commonly referred to as Perth Amboy. This assumption is based upon discussion with officials of the New York-New Jersey Port Authority and their extensive planning and firm commitments to construct a coal port to handle both domestic and export shipments. This port would have ample water depth to service deep-draft colliers for the domestic coal trade in 1991 (John E. Nikolai, Manager, Coal Projects, The Port Authority of New York and New Jersey).

In this application of FNEM, non-coal traffic was preloaded on the rail network using the six traffic densities in the FRA networks (see p. 3-7) expanded by 10% for 1991, that is, 1.1, 5.5, 11, 22, 33, and 55 million tons of two-way traffic per link as per the respective density codes. Coal was then loaded onto the system so that its incremental impact could be analyzed.

6.2 MODEL OUTPUT

6.2.1 Overview

The outputs of the model are traffic volumes on each link and a series of origin-destination pairs and path information for all coal movements. The origins and destinations are given in codes generated by the FNEM algorithm and the path links are given in FRA link identification codes. (The theory and methodology of the model are discussed in Section 2.) Each O-D pair provides a path or a route for that particular coal shipment. An example of two such detailed routes is presented in Figure 6.1. The first is a combined rail-water route from New Castle, Pa., to Middletown, Conn., via Conrail with transshipment at Perth Amboy, N.J., to intercoastal barge. The second is an all-rail CSX Corporation route from Uniontown, Pa., to Riverside, Md. The model output is translated into two reports generated by Report Writer 1 and Report Writer 2,

CARRIERS USED

```
31      1      1      1      1      1      1      1      1      1      1      1      1      1       1
 1      1      1      1      1      1      1      1      1      1      1      1      1      1      21
11
```

O-D PAIR: 278 ORIGIN: 885 New Castle PA DESTINATION: 2175 Middletown CT

		TYPE 1	TYPE 2	TYPE 3	TYPE 4	TYPE 5	TYPE 6
FLOW ON PATH	133	0	0	0	0	0	681000

TRANSPORTATION COST = 1.19677E+01 DELAY COST = 1.89752E+00 TOTAL COST = 1.38652E+01

ARCS USED

```
SUPAC  P0090  P0627  P0792  P0791  P0784  P0785  P0066  P0068  RDG41  RDG49  RDG73  RDG58  RDG64  RDG57
RDG70  P0625  P0762  P0738  P0624  RDG06  RDG20  RDG23  P0056  P0736  P0053  P1041  P0052  LV024  TRS91
WX045
```

CARRIERS USED

```
31      1      1      1      1      1      1      1      1      1      1      1      1      1       1
 1      1      1      1      1      1      1      1      1      1      1      1      1      1      21
11
```

O-D PAIR: 492 ORIGIN: 990 Uniontown PA DESTINATION: 2238 Riverside MD

		TYPE 1	TYPE 2	TYPE 3	TYPE 4	TYPE 5	TYPE 6
FLOW ON PATH	173	0	0	0	0	196503	0

TRANSPORTATION COST = 7.18752E+00 DELAY COST = 3.38852E-01 TOTAL COST = 7.52637E+00

ARCS USED

```
SUPAC  BX243  BX046  BX044  BX042  BX043  BX058  BX058  BX249  BX187  BX188  BX186  BX185  BX184  WM024
WM039  WM015  WM013  WM008  WM008  WM009  WM010  PPL07
```

CARRIERS USED

```
31      2      2      2      2      2      2      2      2      2      2      2      2      2      2
 2      2      2      2      2      2      2     25
```

Fig. 6.1. Two Examples of Detailed FNEM Route Outout from Oil SIP Scenario, 1991

respectively. Report Writer 1 provides, for FUA coal only, the coal sources; destinations (which are the FUA powerplants); demand, by sulfur content; estimated transport and delay costs; the carrier (either the rail system or type of water vessel) and, if the shipment moves by water, the transshipment port. The rail transport costs are based on engineering characteristics of the rail routes and the cost functions described in Section 3.3. The delay costs are based upon time delays in the rail and water systems. Although these delay costs do not add to the actual tariffs, they do represent a cost to the shipper for excess time the shipment of coal requires to travel through the system. Figure 6.2 is a sample page of the report. The two detailed route illustrations in Figure 6.1 are included in this sample page. The complete Report Writer 1 outputs for the Oil SIP and NSPS 1991 scenarios are presented in Appendix E.

Report Writer 2 provides, for each coal-carrying arc (link) in the network, a listing of traffic volumes ordered by the change in the FUA scenario case (Oil SIP or NSPS) versus the Base Case, which assumes no FUA conversion. Thus, the report writer highlights impacts to the transportation system and is discussed in Section 6.3. However, it should be noted that although the FUA scenarios always produce an increase in the total network traffic volume, many individual system links have a lower flow volume under the FUA case. This is the end result of the adjustment of origin-destination pairs exercised by FNEM in arriving at the final, equilibrium solution. The Report Writer 2 outputs for the 1991 Oil SIP and NSPS scenarios are presented as Appendix F.

6.2.2 Summary of Routes

The movement of coal to the FUA powerplants can be separated according to originating rail carrier--Conrail or CSX Corporation. Conrail is the originating carrier for coal moving from the New Castle and State College transportation zones in northwestern Pennsylvania. CSX is the originating carrier for coal sources in the transportation zones of Athens and Portsmouth, Ohio; Clarksburg, West Virginia; Uniontown, Pennsylvania; and Hagerstown, Maryland. Figure 6.3 is an illustration of the Conrail routes from the coal sources to those plants taking final delivery from Conrail and to the ports of Perth Amboy and Curtis Bay, from which water deliveries to FUA plants will be made. Most of the coal moved by Conrail follows a Conrail mainline east through Williamsport and then into Sunbury. At this point the route splits; one segment continues eastward and the other goes south to Harrisburg. At Harrisburg, it splits into two routes, one serving the Baltimore area plants, H.A. Wagner and C.P. Crane and the port of Curtis Bay, and the other serving Edge Moor near Wilmington. The movements continuing eastward from Sunbury split into many routes to serve Cromby, Burlington, Sayreville, Kearny, Bergen, Sewaren, Hudson, Lovett, West Springfield, Mount Tom, and the port of Perth Amboy. A separate route carries coal from the New Castle area on a route north to Lake Erie and along the Lake Erie and Lake Ontario shore lines to Rochester. At this point, coal destined for the Oswego plant follows a route along the lake to the plant. Coal destined for the Albany plant continues eastward on Conrail's "New York State Mainline" through Syracuse, Rome, and Utica to the plant near Albany.

Figure 6.4 is an illustration of the CSX routes from the coal sources to those plants taking final delivery from CSX and to the port of Curtis Bay, from which water deliveries to FUA plants will be made. The route follows the "B&O Mainline", now operated by the Chessie System of the CSX Corporation, eastward into Baltimore where it serves the C.P. Crane and Riverside plants and the port of Curtis Bay.

The plants that will take final delivery by water are shown in Figure 6.5. The plants served by barge moving along the intercoastal waterway from Perth Amboy are Danskammer, Middletown, Glenwood, E.F. Barrett, Ravenswood, Far Rockaway, Arthur Kill, Montville, Devon, Bridgeport Harbor, Norwalk Harbor, Port Jefferson, and Northport. The plants served by collier from Perth Amboy are Mason, Schiller, Salem Harbor, Mystic, New Boston, South Street, Somerset, and Canal. Coal from Curtis Bay is moved by barge on the intercoastal waterway to the plants of Deepwater and Brandon Shores.

The Springdale plant, located in western Pennsylvania, is close to many coal sources. FNEM selected two coal supply regions to provide coal for Springdale; they are New Castle and Pittsburgh, both in Pennsylvania.

6.2.3 Modal Split

All FUA coal movements originate by rail, with 89% on Conrail and 11% on CSX Corporation (see Table 6.1). FNEM forecasted 64% of final coal deliveries to be via water in 1991. Approximately 23.4 million tons of coal will have final delivery via coastal barge or deep-draft collier. The split between barge and collier traffic indicates that slightly more than three-quarters of water traffic will travel by coastal barge for final delivery (see Table 6.2).

6.3 IMPACTS TO TRANSPORTATION SYSTEMS

As previously mentioned, Report Writer 2 output (see Appendix F) highlights impacts to the transportation system by listing all coal-carrying links in the network ordered by changes in traffic volumes of the respective FUA scenarios versus the Base Case. The report also lists, for each link, the coal volume, in tons, of the FUA and Base Case; the preload volume (all

FUA Plant	State	Coal Source	Annual Demand by Coal Type (% Sulfur) (Kilotons) 0.00-0.64%	0.65-1.04%	1.05-1.84%	1.85-2.24%	2.25-3.04%	3.05+%	Transport Cost ($/ton)	Delay Cost ($/ton)	Carriers
Middletown	CT	New Castle, PA	0.0	0.0	0.0	0.0	0.0	681.0	11.97	1.90	Conrail Perth Amboy, NJ Intercoastal Barge
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	136.0	681.0	11.54	1.85	
Edge Moor	DE	State College, PA	0.0	0.0	0.0	0.0	838.0	0.0	6.86	0.51	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	838.0	0.0	6.86	0.51	
Mason	ME	New Castle, PA	0.0	0.0	0.0	436.0	0.0	0.0	13.61	2.47	Conrail Perth Amboy, NJ Collier
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	436.0	0.0	0.0	13.61	2.47	
Brandon Shores	MD	Uniontown, PA	0.0	0.0	0.0	0.0	2288.2	0.0	8.31	0.51	CSX Corp. Curtis Bay, MD Intercoastal Barge
Brandon Shores	MD	Johnstown, PA	0.0	0.0	0.0	0.0	746.8	0.0	7.35	0.45	CSX Corp. Curtis Bay, MD Intercoastal Barge
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	3035.0	0.0	8.07	0.49	
Riverside	MD	State College, PA	0.0	0.0	0.0	0.0	137.0	0.0	6.46	0.49	Conrail Power Plant RR Link
Riverside	MD	Uniontown, PA	0.0	0.0	0.0	0.0	196.5	0.0	7.19	0.34	CSX Corp. Power Plant RR Link
Riverside	MD	Johnstown, PA	0.0	0.0	0.0	0.0	27.5	0.0	6.23	0.28	CSX Corp. Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	361.0	0.0	6.84	0.39	
Crane, C.P.	MD	State College, PA	0.0	0.0	0.0	0.0	859.0	0.0	6.46	0.49	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	859.0	0.0	6.46	0.49	
Wagner, H.A.	MD	State College, PA	0.0	0.0	0.0	0.0	618.0	0.0	6.46	0.49	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	618.0	0.0	6.46	0.49	

Fig. 6.2. Sample Page from Report Writer 1 - Oil SIP Scenario, 1991

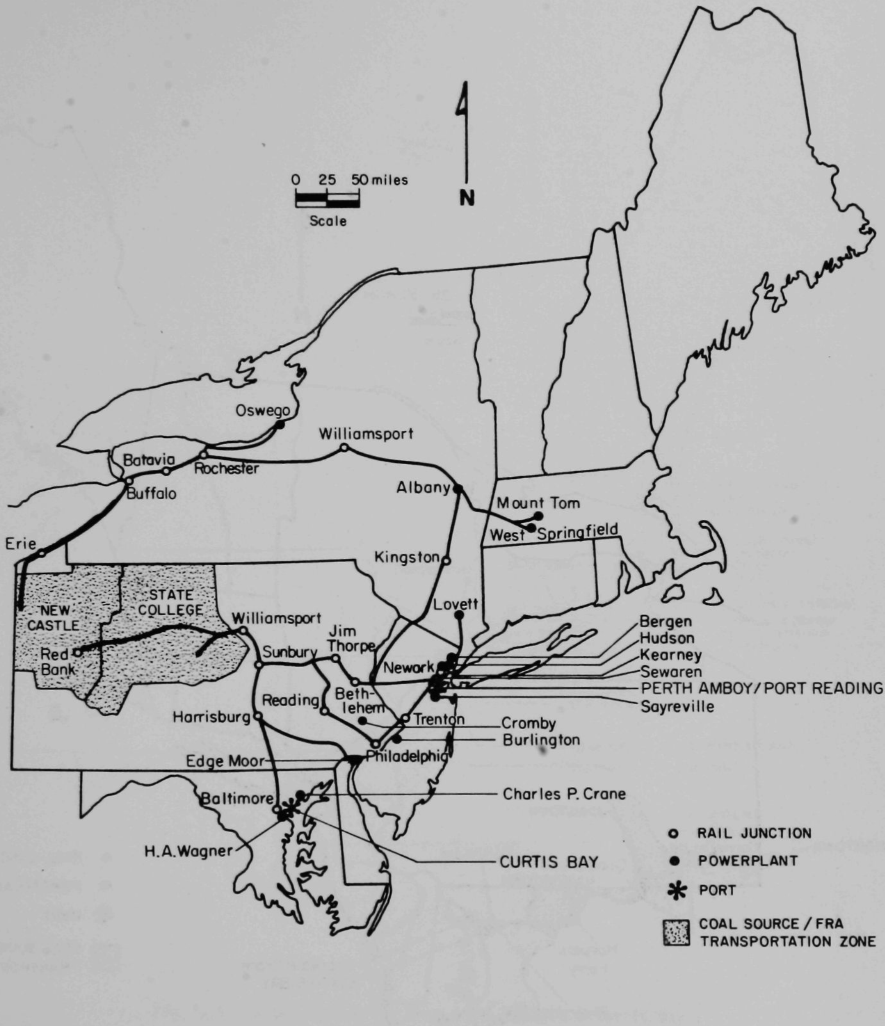

Fig. 6.3. Conrail Routes to Powerplants Receiving Final Delivery by Rail and to Perth Amboy and Curtis Bay

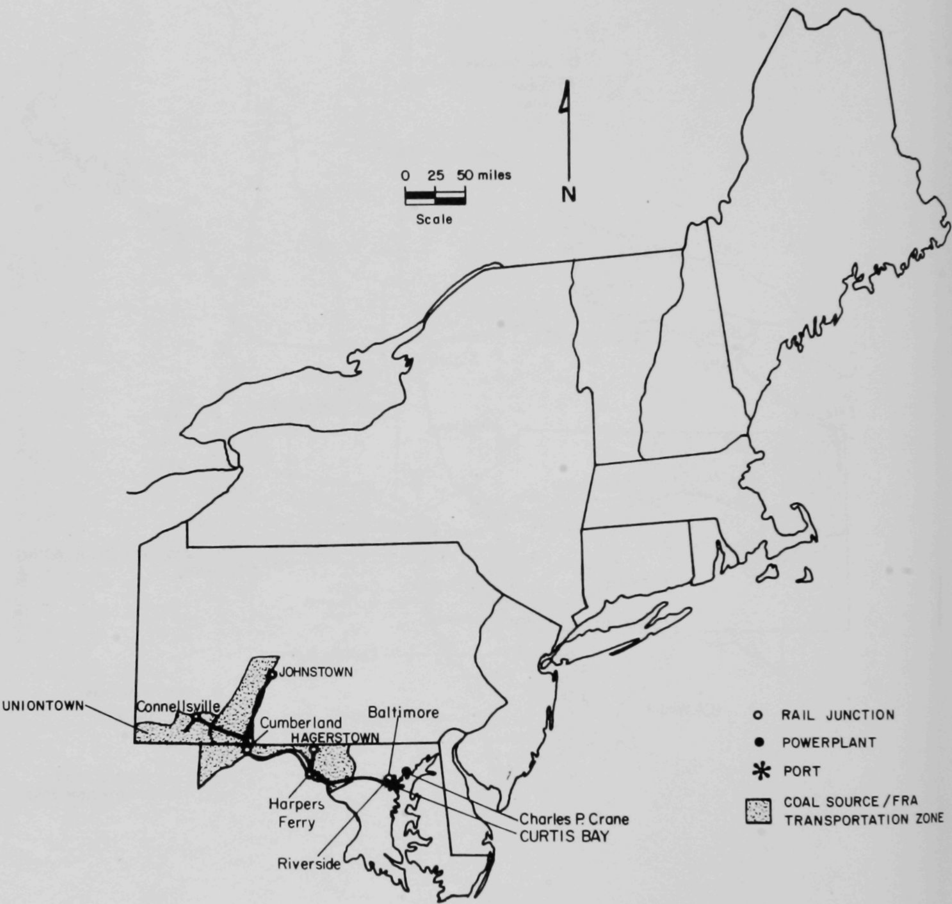

Fig. 6.4. CSX Corporation Routes to Powerplants Receiving Final Delivery by Rail and to Curtis Bay

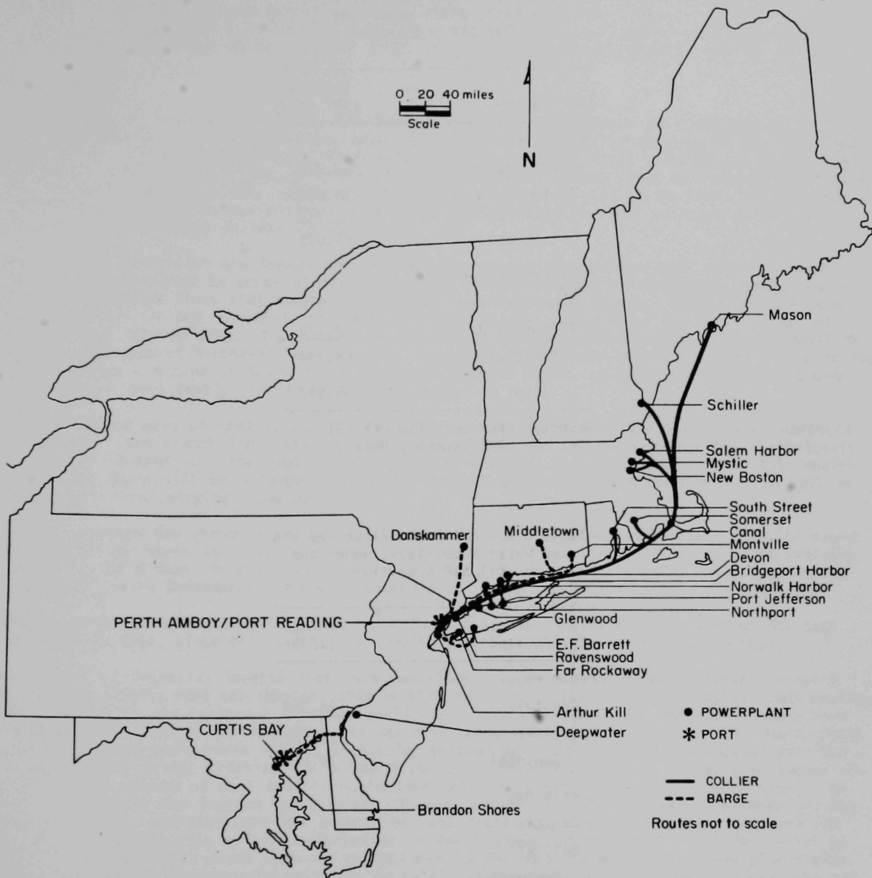

Fig. 6.5. Water Deliveries from Perth Amboy and Curtis Bay

Table 6.1. FUA Coal Movements by Rail, 1991, under the Oil SIP Scenario

Rail Carrier	Tonnage (10^3 ton)
Conrail	
Direct Delivery	12,212
To Perth Amboy	19,858
To Curtis Bay	523
Subtotal	32,632
CSX Corporation	
Direct delivery	979
To Curtis Bay	2,975
Subtotal	3,954
Total	36,547

Source: FNEM outputs, Oct. 31, 1981, summary data.

Table 6.2. FUA Coal Deliveries Via the Water Mode, 1991, under the Oil SIP Scenario

Port/Vessel Type	Tonnage (10^3)
Perth Amboy	
Coastal	14,152
Collier	5,706
Subtotal	19,858
Curtis Bay	
Coastal	3,498
Collier	0
Subtotal	3,498
Total	23,356

Source: FNEM outputs, Oct. 31, 1981, summary data.

non-coal traffic); the total FUA case volume, and finally, the ratio of total FUA case volume to estimated link capacity. All traffic volumes are two-way, annual values, in millions of tons. The link capacities used are practical limits defined as 2/3 of the F value (theoretical capacity parameters) of Equation 1 in Section 3.3. In some instances, there are zero values of volume/capacity. These always apply to water links where the network capacity is taken as infinite.

6.3.1 Rail

Only two out of a possible thirteen New England powerplant candidates are predicted to use the rail mode for their final deliveries; this emphasizes the difficulty of shipping via rail into New England. (The two powerplants that selected rail for their final delivery can accept coal deliveries only by rail.) The rail carriers are forecasted to make final delivery on 13.2 million tons in 1991. Although only 36% of FUA coal final deliveries will be by rail, all FUA and non-FUA coal travels on the rail system at some point, either to final delivery or to a transshipment port for final delivery by water.

Impacts and congestion are forecasted for certain branch lines of the rail system. Severe impacts are predicted to occur along branch lines between Sunbury and Bethlehem, Pennsylvania, and on the branch lines that approach the ports in northern New Jersey. FNEM forecasted that the quantities of FUA conversion-related coal hauled over these lines may be as great as 27.5 million tons in 1991. This amount of forecasted tonnage would be difficult for Conrail to haul in this area of Northeast Pennsylvania. Possible remedies for this congestion are upgrading track, adding a second or third track along the current route, or diverting the traffic over other longer, more costly (in time and money) routes.

Another severe area of traffic congestion occurs on branch lines in the port area of northern New Jersey. The branch lines that approach Port Reading and Perth Amboy have had historically low levels of traffic. The high demand for use of the coal transshipment ports in this region means that there will be a large increase in traffic for both FUA and non-FUA coal in 1991 on some branch lines serving these ports.

In the northern New Jersey area, congestion on Conrail branch lines will result from increased traffic to the ports and direct delivery to powerplants. These branch lines serve as delivery routes to the Hudson, Kearny, and Bergen powerplants in the Newark area as well as a traffic connection to the Danskammer and Lovett powerplants in New York state.

There should be no negative impacts to the Conrail New York-State-Mainline due to FUA coal shipments in 1991, since this mainline has multiple tracks and a high traffic density.

Two areas of potential impacts that were described by Transportation and Economic Research Associates (1980b) were not substantiated in this analysis. It was thought possible that routing coal traffic on the Northeast Corridor would cause problems for Amtrak operations and a more rapid deterioration of the road bed. It was also thought that rail deliveries into New England and Long Island could cause impacts in passing through New York City on the Northeast Corridor. Since the only bridge crossing the Hudson River is in Selkirk, New York, it was also suggested that a large amount of coal traffic would take this route and perhaps cause congestion. The rail routes into New England and onto Long Island were not used because water delivery was the preferred mode, and therefore the impacts of rail traffic on the Northeast Corridor did not occur. The powerplants under consideration in New England receive their final deliveries by water in all possible cases with two exceptions--the Mt. Tom and West Springfield powerplants, which are capable of receiving coal only by rail. These plants were assigned routings over the Hudson River at Selkirk. These two all-rail deliveries are in Western Massachusetts, which is not close to the Northeast Corridor, and they do not affect Amtrak passenger services nor are they large enough to cause congestion at the Selkirk Bridge.

Final delivery to the Edge Moor powerplant in Delaware does intersect with the Northeast Corridor for a short distance. Final deliveries enter the corridor at Perryville, Maryland, and move approximately 41 miles northeastward into the Wilmington area for delivery to the powerplant. The large proportion of final delivery via water to Long Island and New England powerplants is discussed in the following section.

6.3.2 Water

Of the predicted 36.5-million-ton coal demand for the FUA candidate powerplants in 1991, 64% will have final delivery via water. Approximately 23.4 million tons will move by either barge or collier to the candidate powerplants. Final delivery is by water for all candidate powerplants on Long Island and in New England (except where the powerplants did not have access to a navigable water channel). Coastal barge deliveries were chosen to Long Island, Connecticut, and New York City powerplants. Deep-draft colliers served the northern New England powerplants.

In the northern New Jersey area, Port Reading is the only presently operating rail-to-water coal transshipment port. Port Reading is limited by the 17-foot depth of water in the adjacent channel and thus only allows coastal coal barges (Transportation and Economic Research Associates, Inc., 1980, p. 5). The combined capacity of Port Reading and the new port, Perth Amboy, should be capable of providing adequate service to those FUA powerplants that obtain coal via water. Historically, coal ports have had logistical problems with their rail yards and lack of storage capacity. The new expansion port at Perth Amboy should overcome this problem with a loop track and large storage capacity. The new port and the existing Port Reading are approximately 5 miles apart; thus when they both use the same approach route, there will probably be congestion. Approximately 20 million tons of coal is predicted to move to these ports for transshipment.

The planned New York expansion port at Perth Amboy becomes important for 1991 forecasted deliveries to northern New England candidate powerplants. Since this planned port will be capable of loading deep-draft vessels, it has this advantage over Port Reading, which will be important for coastal barge trade.

Curtis Bay, which is owned and operated by the Chessie System, will be a transshipment point for coal for coastal barge traffic for coal conversion in 1991. This port also is used for coal export trade, similar to other coal ports. There have been large delays at Curtis Bay since the spring of 1980; the Coal Exporters Association (1980, p. 10) indicates that on May 27, 19 vessels were waiting to load at Curtis Bay. Assuming that these delays remain until 1991, the Curtis Bay facility will most likely have additional delays resulting from the FUA conversions. The delays probably will occur in the rail yards and not at the pier, since domestic traffic currently has a loading priority over export traffic.

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APPENDIX A. THE DATA RESOURCES INC. (DRI) COAL MODEL

A.1 DESCRIPTION OF THE MODEL

The DRI coal model is a resource-based tool for analyzing issues in coal consumption, production, prices, and distribution. The model considers 18 producing states, 13 consuming regions, 8 demand sectors, 2 types of mining, and 36 types of coal--6 regional averages of Btu content, and 6 sulfur classes (see Table A.1). The model generates annual projections. The flexible structure of the model allows users to tailor the model to their particular needs. For example, users may interactively change the definition of demand regions by specifying regional demands, emission standards and transportation costs that are consistent with their regional aggregation. The model provides those interested in coal with a consistent methodology for investigating changes within the coal industry, including the regulatory and economic environment of the coal industry.

The coal demand forecast input to the DRI model may be either the user's own projection or the DRI energy model's forecast. Since the DRI energy core model is interlinked with the macroeconomic model, it is internally consistent with the broad forecasts of the economy.

The DRI energy core model considers five coal-consuming sectors. The largest (73% of total production in 1978) is the electric utility sector. Regional electric utility coal demand forecasts are derived from a structural econometric model. This model accounts for types of generating capacity, fuel types, fuel prices, and assumptions on the rate of return. Other factors taken into consideration include weather degree days and planned capacity expansion.

The other consuming sectors considered are the metallurgical, industrial, household/commercial, and export sectors. Coal consumed for producing coke (metallurgical coal) is forecast in the energy model as a function of industrial output in the iron and steel sector. Industrial non-coking coal and household and commercial coal use are forecast using structural demand equations where industrial output (by sector), relative energy prices, and other variables are included in the formulation. The energy model provides national annual demand forecasts for these sectors. The figures were regionalized by using weights obtained from historical distribution patterns. Finally, total regional coal demands were obtained by summing the regional demands of all sectors.

The coal demand forecasts, emission control standard, and the transportation costs are parameters in the coal model and may be altered by the user. The regional demands for coal are matched by the model with the least-cost source of supply while satisfying sulfur emission control standards. Costs include minemouth cost of coal, transportation, and (if applicable) scrubbing cost. The model minimizes the total delivered cost of coal to the total system (all regions).

The majority of coal consumed in 1977 was either purchased through previously signed contracts or came from captive mines (user-owned coal mines). Therefore, the actual distribution of coal may not be optimal as long as old contracts are in effect and as long as captive mines are productive. The DRI optimization process accounts for these constrained coal movements and allocates only unconstrained coal.

Metallurgical coal demands and coal exports are allocated to supply regions and sulfur category based on historical distribution trends. This allows the optimization model to consider domestic steam coal demands and require those demands to meet sulfur emission standards.

The DRI coal model specifies 13 consuming demand regions, but each region usually includes several states. The Northeast Regional Environmental Impact Statement includes only the 11 states of the northeastern United States. It was therefore necessary (and the model permits this) to specify certain DRI demand regions as individual states. In addition to the region definitions the emission scenarios, the time frame for analysis (annually, 1985 thru 1991), and the quantities of coal required by the converted plants for each year were also specified (Table A.2).

A base case (called base case) was established that did not include the demand that results from conversion of the 42 plants from oil to coal. The emission scenario for the base case was the current situation as embedded in the DRI model if no plants were converted to coal.

Two other emission scenarios were developed to analyze the coal flows among the supply and demand regions; these were called the Oil SIP and 1977 NSPS cases. These scenarios used the State

Implementation Plan (SIP) air quality standards for oil burning and New Source Performance Standards, respectively. These two cases included the increase in demand from conversion of plants, while the base case excluded conversions. The Oil SIP and 1971 NSPS emission standards were applied to the coal demand resulting from conversion; base-case emissions are added to these emissions to estimate the total for the region.

Table A.1. DRI Coal Model Input Parameters

Supply Regions

Notation	Regional Name	Regional Designation	States Included	Regional Btu Content of Coal (10^6 Btu/ton)
A	Northern Appalachia	NAPP	MD, OH, PA, Northern WV	24.1
B	Southern Appalachia	SAPP	AL, Eastern KY, TN, VA, Southern WV	23.7
C	Midwest	MIDWEST	IL, IN, Western KY	22.0
D	Montana-Wyoming	MT-WY	MT, WY	17.2
E	Colorado-Utah	CO-UT	CO, UT	21.9
F	Arizona-New Mexico	AZ-NM	AZ, NM	20.2

Demand Regions

Notation	Regional Name	Regional Designation	Original DRI Regions States
1	New England	NENG-ME, NH, VT	MA, ME, VT, RI, NH, CT
2	Middle Atlantic	MATL-PA	PA, NJ, NY
3	South Atlantic	SATL	DE, MD, DC, VA, WV, GA, FL, SC, NC
4	East North Central	ENC	OH, WI, IN, MI, IL
5	East South Central 1	ESC1	KY, TN
6	East South Central 2	ESC2-MA	AL, MS
7	West North Central	WNC-CT	KS, NE, ND, SD, MN, IA, MO
8	West South Central 1	WSC1-MD	OK
9	West South Central 2	WSC2-DE	TX, AR, LA
10	Mountain 1	MTN1-RI	NM
11	Mountain 2	MTN2-NY	MT, CO, WY, ID, UT
12	Mountain 3	MTN3-NJ	NV, AZ
13	Pacific	PAC	CA, OR, WA, AK, HI

Consuming Sectors: No.	Consuming Sectors: Name	Sulfur Content Categories: Notation	Sulfur Content Categories: Actual Sulfur Content
1	Electric utility	5	0.00 to 0.64%
2	Metallurgical coal	10	0.65 to 1.04%
3	Industrial noncoking coal	15	1.05 to 1.84%
4	Household commercial	20	1.85 to 2.24%
5	Export	30	2.25 to 3.04%
		3&	3.05 and above

Table A.2. Northeast Region States FUA-Converted Utility Capacity and Coal Demand

DRI Region Designation	State(s)	Transportation Centroid	Oil[a] SIP	NSPS[a]	Converted Coal Capacity, MW and Coal Demand (10^3 ton)						
					1985	1986	1987	1988	1989	1990	1991
1-NENG	ME,NH,VT	Portsmouth, NH	1.21	0.6		150 (425)	299 (881)	299 (881)	299 (881)	299 (881)	299 (881)
2-ESC2	MA	Boston, MA	0.85	0.6		417 (959)	417 (959)	989 (2,067)	2,291 (5,028)	2,291 (5,028)	2,435 (5,327)
3-WNC	CT	New Haven, CT	0.28	0.6	1,163 (2,459)	1,377 (2,911)	1,458 (3,149)	1,458 (3,149)	1,458 (3,149)	1,458 (3,149)	1,458 (3,149)
4-MTN2	NY	New York, NY	0.69	0.6	792 (2,110)	2,638 (5,968)	4,545 (10,705)	4,983 (11,923)	5,563 (13,262)	6,231 (14,903)	6,231 (14,903)
5-MTN3	NJ	Newark, NJ	0.22	0.6			626 (1,528)	1,702 (3,948)	2,272 (5,142)	2,272 (5,142)	2,272 (5,142)
6-MATL	PA	Allentown, PA	0.28	0.6						367 (836)	946 (2,593)
7-WSC1	MD	Baltimore, MD	0.45	0.6			610 (1,589)	2,018 (5,104)	2,018 (5,104)	2,018 (5,104)	2,018 (5,104)
8-WSC2	DE	Wilmington, DE	0.54	0.6						389 (877)	389 (877)
9-MTN1	RI	Providence, RI	0.54	0.6							100 (305)

[a]Emission standard in lb S/10^6 Btu.
Coal heat content is 23 × 10^6 Btu/ton.

APPENDIX B. METHODOLOGY TO CORRECT NATIONAL NETWORK DATA BASE

The National Network Data Base (NNDB) is an analytical model and information data base developed by the Federal Railroad Administration (FRA), U.S. Department of Transportation. The original purpose of developing this rail-link by rail-link data base was for analyses of bankrupted railroads in the Northeast quadrant of the United States in the early 1970s. After the initial effort was completed, development of a national network data base began for the remaining sections of the country. (The national model excludes the Alaskan Railroad, and Hawaii does not have a commercial freight rail system.)

The NNDB contains approximately 18,000 nodes and 15,000 links. The network model contains software programs that are employed for railroad analysis and planning. (The Northeast Regional Environmental Impact Study does not use these programs.) There are ancillary data files that can interact with the NNDB to assist in analyses. These data files contain longitude and latitude coordinates for computer mapping, rail yard locations and data, historical commodity flows per link, and freight station locations.

The core of the NNDB is the link and node characteristics. Each link in the data base has its own file of link attributes describing the characteristics of that particular segment of track. The nodes do not have corresponding files, but they are coded by unique seven-digit numbers that describe its location and purpose.

B.1 PROBLEM AREAS

Due to the size of the data base and the magnitude of information it contains, there are continual problems with the data files. Any available magnetic tape copy of the NNDB contains deficiencies. These errors are either links that are missing or links that are disconnected from their proper nodes.

The original NNDB had constraints in the software that did not allow more than four links to join one node. To compensate for this weakness, the data base contains numerous dummy links and dummy nodes, especially in the urban areas where four or more tracks join. These dummy links had values of zero but their incorporation did increase the size of the data base and computation time.

The rail systems of the United States are dynamic. Each rail company has non-profitable links that it abandons or sells to another rail company. Rail systems presently are going through a stage of mergers, where two or three railroads form a new and larger rail system. New rail lines recently were constructed in the coal-producing regions of the West. All of these changes need to be reflected in the NNDB.

B.2 METHODOLOGY TO IMPROVE AND CORRECT THE NNDB

The methodology that was employed to verify the junction connectivity required that the node numbers and Link Identification Codes (LICs) of each junction be examined. For each LIC entering a junction, the node numbers were extracted and a diagram of that junction was plotted. The node numbers were compared and cross-referenced with other incoming LICs to verify their connectivity, i.e., connected LICs shared the same node number. This was repeated for each complex/urban junction.

The method used to check for missing rail links required cross-referencing among various data sources. The first data source was a listing of links not in the available NNDB tape. The second source contained a listing of approximately 1500 links that had one node as a stub end. The third source was the master FRA LIC file. Each rail link in question was compared among these sources to verify that links were actually stub-end branch lines or disconnected mainlines. If proven to be a disconnected mainline, the connectivity issue was resolved. If there was a missing link, the link and its characteristics were replaced in the data base.

Another task in the correction effort incorporated abandoned rail links that were approved by the Interstate Commerce Commission. These approved abandonments included decisions as recent as July 1, 1981. The corresponding LIC for the abandoned rail line was searched and removed from the current data base.

Improvements to the acquired network data based centered on two primary tasks. Current free speeds were added to the LICs remaining in the data base and the dummy nodes and dummy links in the urban areas were removed.

The speed data were obtained via a telephone survey of the major national railroads in the study region. The appropriate operating personnel in these railroads were interviewed. The mainline speeds for each railroad were obtained on a route-by-route basis. Essentially, this referred to a series of LICs between major cities. The branch lines for the surveyed railroads were treated differently. The major branch lines, which had speeds ranging between 25 and 40 mph, were obtained in a fashion similar to mainline speeds--route by route. The light-density branch lines were grouped together and assigned a speed that was assumed reasonable by the operations personnel surveyed.

Software programs were developed to eliminate and consolidate unnecessary dummy links. A program entitled "Reduce" eliminated the dummy nodes and thus the LICs "collapsed" into the actual physical node for that particular urban area.

To update the data base to consider recent and proposed mergers, a new numbering code was developed for the new rail systems. The same code was assigned to two or more rail companies that recently had merged or had announced a merger. The links within the new system maintain the original rail company's identification.

APPENDIX C. RAIL AND WATER FREIGHT COST FUNCTIONS

C.1 THE CONCEPT OF COST

The ease with which the term costs often is used is very misleading, in that it implies that there is a single cost associated with providing goods or a service. It is true that in principle it may be possible to identify a single total cost to society resulting from producing a product or service such as transportation, but the term usually refers to the cost borne by a particular person, group or organization, and thus may be very different from the total cost to society. The multifaceted characteristic of cost arises because in general different costs are borne by different persons or groups, and usually such persons or groups are interested only in those costs that accrue to them.

The various groups can be identified as follows:

- Users of the system
- Owners and/or operators of the system
- Affected non-users of the system (such as those living in residences near the facility)
- Government at various levels
- The region as a whole

This list is in no way meant to be exhaustive or to imply that the groups are mutually exclusive. On the contrary, a person may experience a certain set of costs associated with transport as a result of his/her use of the system and a quite different set of costs as a result of living near a link in the system, thereby experiencing non-user costs. The various groups are presented in Table C.1, along with typical examples of the costs experienced by each group.

In this appendix, the discussion concerns much more direct costs, primarily those that are reflected in identifiable market transactions where money changes hands and places a value on resources used (e.g., fares, tolls, freight, travel time, loss and damage of freight, etc.). It may be difficult to associate a monetary value with many of the costs that could be considered, such as the time travelers spend in traveling, as the traveler is not directly paid (or charged for) the travel time.

C.2 COST-ESTIMATING METHODS

There are basically two approaches to estimating costs, although in practice a combination of both often is used: (1) the engineering unit cost method and (2) the statistical cost or cost-output method.

C.2.1 Engineering Unit Cost Method

This method actually traces the process, first estimating the amount of physical resources needed and then applying prices to yield the total cost. The first step is to develop a relationship between the various scarce resources to be used and the nature of the transportation capacity and service to be provided. The advantages of the engineering unit cost approach are essentially that it enables exploration of changes in the technology and also examination of particular components of costs. Since the technological relationships are explicitly taken into account, any change in the technology can be treated, as long as the price of any new or modified items can be estimated or ascertained.

C.2.2 Statistical Cost Methods

Statistical cost models are developed with the aid of data on the costs incurred in actual transport systems. The usual procedure is to specify an expected mathematical relationship between cost and output, in which the functional form of the relationship is specified but the numerical values of the parameters are not. Then data on the actual costs incurred for the types of systems being considered are examined and the parameter values are estimated, usually using statistical regression or related methods. Often if the hypothesized model with the initial estimate of parameter values does not adequately predict or reproduce these costs, the model is modified or refined until a satisfactory degree of correspondence is achieved.

The cost models are different for different modes and technology. Road-costs models used for trucks are quite different from those used for railroads, or for barges or ships (waterway transportation). Truck firms do not have to own the right-of-way on which they operate, whereas railroads do. A clear picture of variation in cost by different modes for both passenger and freight transportation is given in Tables C.2 and C.3.

Table C.1. Groups that Experience Different Transport Costs

User

- Direct prices (fares, tolls, freight, etc.)
- Time consumed (travel time)
- Discomfort of travelers (fatigue, etc.)
- Loss and damage of freight

System owner-operator

- Direct costs of construction, operation, maintenance

Nonuser

- Changes in land value, productivity, etc.
- Environmental degradation (noise, pollution, esthetics, etc.)

Government

- Subsidies and capital grants
- Loss of tax revenues (e.g., when road or other publicly owned facility replaces tax-paying land use)

Region

- Usually indirect, through reorganization of land uses, altered rate of growth, etc.

From Morlok (1978, p. 347).

Table C.2. Typical Costs for U.S. Intercity Passenger Service

	Long-Run Marginal Cost, 1955		Average Total Cost, 1974 (cents/passenger-mi)
	Cents/Seat-Mi[a]	Cents/ Passenger-Mi[b]	
Airplane	1.8-3.2	3.6-6.4	7.3
Automobile	0.63-1.33	1.9-4.0	7.7[c]
Bus	1.25	2.5	3.9
Railroad			
Day coach	1.3-1.4	2.6-2.8	
Overnight coach	2.2-2.3	4.4-4.6	
Parlor	2.7-3.0	5.4-6.0	
Pullman	5.0-6.0	10.0-12.0	
All service			13.1[d]

From Morlok (1978, p. 402).

[a]Air costs are for jet aircraft and trips over 1000 mi. Auto costs are for a six-seat auto.

[b]Using average load factors of 50%, except for auto and rail accommodations, 33.3%.

[c]1969 cost increased by 30%.

[d]For Amtrak, including operating costs (11.9 cents passenger-mi) plus 10% to reflect normal investment level in contrast to the higher level currently experienced.

Table C.3. Typical Costs for U.S. Intercity Freight Carriers

Type of Carrier and Commodity	Long-Run Marginal Costs, 1952-1955 (cents/ton-mi)[a]	Average or Typical Revenue, 1973 (cents/ton-mi)
Air--merchandise	Unavailable	23.31[b]
Inland water		
Bulk	0.105-0.332	0.25-0.80[c]
Merchandise	0.55-1.85	Unavailable
All commodities	Unavailable	0.378[b]
Pipeline--oil	0.513-0.581	0.290[b]
Railroad		
Bulk	0.390-0.810	0.41-1.60[c]
Merchandise	0.722-1.511	Unavailable
All commodities	Unavailable	1.62[b]
Trailer on flat car	0.875-1.83	Unavailable
Truck		
Merchandise (TL)	1.82-4.90	1.93-3.02[c]
All commodities (TL and LTL)	Unavailable	8.24[b]

From Morlok (1978, p. 403).

[a]Ranges are for 0 to 100% empty returns, 200 to 1500 mi, and for rail operations include 30% added to line-haul costs to reflect yard and local freight costs.

[b]Complete current data on costs are not available; hence revenue is used as a surrogate for 1973. Revenue averages reflect differences in commodity types, shipment sizes, length of haul, and that the data for rail and truck (all commodities) are for Class I carriers only, for water are for ICC-regulated lines only, and air data are for scheduled domestic carriers only.

[c]All revenues for 1970.

[d]Costs of independent owner-operator truckers carrying primarily merchandise.

C.3 RAIL COST MODELS

Railroad is an important mode of transportation for both freight and passengers. In the United States, for example, railroads handle more than 35% of all freight (measured in ton-miles). Since the railroad industry has a large investment in equipment and a sizeable number of employees, its management faces a complex decision-making environment where a broad spectrum of planning and operational issues have to be settled. As in many other transportation environments, the rail transportation system may be regarded as a network. The links of this network refer to lines of track where long-haul movements of traffic take place. The nodes refer to stations where carriers pick up or deliver traffic, or yards where trains are formed and classified. The various activities performed in a yard are referred to as "yard activities." The decisions affecting the movement of a train between yards are known as "line activities." In the following sections, only the "yard cost" and the "line-haul cost" incurred by a railroad are considered.

C.4 YARD COST MODELS

According to data gathered by Reebie Associates (1972), the average rail car spends about 56% of its time in various yards and spends only 16% of its time actually moving in trains. This underscores the importance of representing yard activities if railroad operations are to be reflected with any reasonable degree of accuracy. Here, yard models are sought that give the following:

- Yard delay or put-through time of a car
- Operating cost in dollars per car or per ton

A discussion of the yards and various yard activities is useful before a discussion of the various models.

C.4.1 Yards and Yard Activities

One of the best ways of classifying yards is by size, structure, and resources, emphasizing those elements that cause congestion or delay to the progress of freight railcars through the yard. The following types of yards exist in most railway systems:

- Simple yard
- Single-ended flatyard
- Double-ended flatyard
- Directional flatyard
- Humpyard

This ordering is from the smallest to the largest yards, with each type shown schematically in Figure C.1.

Hump yards are the largest and most complex yards. Their dominant characteristic is the efficiency with which the classification operation is performed. In a flatyard, the yard engine moves the block of cars being classified back and forth over the classification lead, with the yard crew setting the switches so as to direct each car onto the desired classification track.

In a hump yard, each car is released from the train at an elevated point. The individual cars roll through the switching network onto the desired classification track. The necessary switching and retarding operations are highly automated in most hump yards. The classification and train assembly operations are always separate in a hump yard.

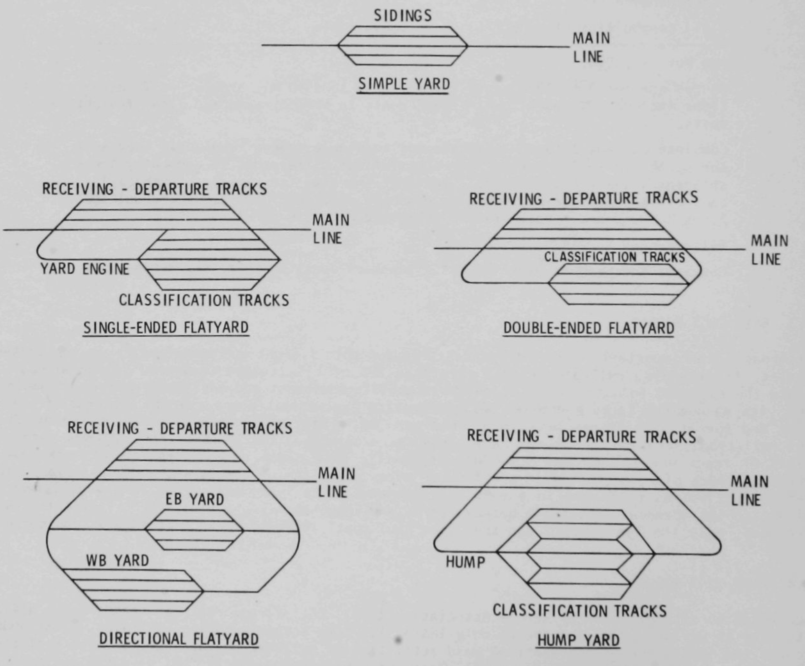

Fig. C.1. Types of Rail Yards. Redrawn from Petersen (1977a).

The various yard activities can be grouped into the following major categories:

- Receiving and inbound inspection
- Classification or sorting
- Train marshalling or assembly
- Outbound inspection and departure

The modeler may correspondingly break up the yard into subsystems involving the operations listed above. Once the yard subsytems are clearly defined, queueing or simulation models may be used to provide information on the behavior of each subsystem.

C.4.2 Yard Delay Models

Although many yard delay models have appeared in the literature, most of them require a detailed knowledge of the yard characteristics and operations. They are aimed at operator optimization of yard activity and as such are not relevant to this study. The models presented below are the ones that are general enough to be applicable to a region-wide study.

C.4.2.1 Model 1

The simplest yard delay model is one that specifies a constant put-through time. Such a model was developed by Bronzini (1979a). Bronzini reports a constant delay of 12.28 hours, for all yards. This is, of course, a large simplification of reality. Each yard varies in size, type, available resources, the amount of traffic handled, etc.

C.4.2.2 Model 2

This model was suggested by Petersen (1977a,b) presented in a series of papers. Petersen provides a systematic analysis of all the delay terms. For the yards under investigation, Petersen concludes that operations--receiving and inbound inspection and outbound inspection and departure--are not bottlenecks and can, therefore, be modeled realistically by fixed service times (the amount of time required is not significant and not highly variable). However, the classification and assembly operations have been explicitly modeled by queueing theory. He suggests several possible models, including:

M/G/1: Poisson arrivals of cars on trains, a general service time distribution, and one server;

M/M/S: Poisson arrivals, exponential service times, and s servers;

M/D/S: Poisson arrivals, deterministic (constant) service times, and s servers.

Thus, we can say that the average time in the yard is the sum of delays due to classification, assembly, and a constant term to account for inbound and outbound inspection delay, as shown in Equation 1 below:

$$T_Y = T_I + T_C + T_A , \tag{1}$$

where T_Y = average time in yard,

T_I = inbound and outbound inspection time,

T_C = average delay for classification, and

T_A = average connection/assembly delay before outbound inspection and departure.

Here, T_I is a fixed service time, depending upon the personnel and facilities available at each yard. This information can be taken from the yards or from the various railroad statistics presented by the American Association of Railroads (AAR), which will give the average inspection time (inbound and outbound) per car or per train.

Petersen reports that the time to classify a train depends on the most heavily utilized classification engine, and is given as

$$T_C = A_C + B_C \, (\max_i \gamma_{Ci}) \ell / \beta , \tag{2}$$

where A_C = the standard time to pull a train and initiate classification,

B_C = the standard time to make a classification switch,

ℓ = the average train length in cars,

β = the average number of cars per cut,

γ_{Ci} = the expected number of classification switches performed by engine per cut through the yard, and

$$\gamma_{Ci} = p_i \left[1 + \sum_{j=1}^{r} \frac{(p_{ij}/p_i)^2}{(1 - p_{ij}/p_i)} + \frac{p_{i+1}^2}{1 - p_{i+1}}\right]^{-1} . \tag{3}$$

In Equation 3, p_i is the probability that a cut will be handled by engine i and is given as

$$p_i = \sum_{k=i}^{m} \sum_{j=1}^{r_k} p_{kj} \qquad \text{for } i = 1,2,\ldots m \text{ and } p_{m+1} = 0 . \tag{4}$$

In Equation 4, p_{kj} is the probability that a cut will be switched onto track j and is given as

$$p_{ij} = \sum_{k=1}^{n_{ij}} p(b_{ijk}) \qquad \forall i,j , \tag{4a}$$

where b_{ijk} = block numbers for $k = 1,2,\ldots.n_{ij}$, and

n_{ij} = blocks assigned to a track.

Here we have let v_i be the number of classification tracks (or differently used groups of tracks) associated with engine i. Similarly, the time to assemble an outbound train is

$$T_a = A_a + B_a\ell + C_a\gamma_a\ell/\beta , \tag{5}$$

where A_a = the standard fixed time to assemble a train,

B_a = the standard assembly time per car,

C_a = the standard time for the assembly engines to make a switch,

ℓ,β are the same as defined above,

γ_a = the total number of assembly switches per cut through the yard, and

$$\gamma_a = \sum_{i=1}^{m} \sum_{j=1}^{r_i} p_{ij}\, \gamma_{aij} , \tag{6}$$

where γ_{aij} = the proportion of cuts on track j of engine i that are reswitched.

This is given as

$$\gamma_{aij} = \begin{cases} \left[1 + \sum_{k=1}^{n_{ij}} \frac{(p(b_{ijk})/p_{ij})^2}{1 - p(b_{ijk})/p_{ij}}\right]^{-1} & n_{ij} > 1 , \\ 0, \text{ otherwise} & \end{cases} \tag{6a}$$

where $p(b_{ijk})$ and p_{ij} are the same as given in Equation 4a.

It is assumed in the above that sufficient standing room (track capacity) is available to perform the required switching operations. If there is an insufficient number of departure tracks, then the effective train assembly rate is given by

$$\mu_a = \min\{1/T_a, n_d/(T_a + T_o)\} , \qquad (7)$$

where n_d = the number of departure trucks and

T_o = expected outbound inspection and departure time.

The effective rate of classification is given by

$$\mu_C = q/t_C , \qquad (8)$$

where q = the probability that the system is not blocked due to classification storage

$$= \pi^{m}_{i+1} \pi^{r_i}_{j=1} q_{ij} , \qquad (9)$$

where q_{ij} = the probability that the number of arrivals is less than or equal to the standing capacity of the track

$$= \sum_{k=0}^{\ell_{ij}} f_{ij}(k)G_{ij}(\ell_{ij}-k) \qquad (10)$$

$$= \sum_{k=0}^{\ell_{ij}} f_{ij}(\ell_{kj}-k)q_{ij}(k) , \qquad (11)$$

where $F_{ij}(k)$ and $G_{ij}(k)$ are the cumulative distribution functions for $f_{ij}(n)$ and $g_{ij}(n)$, respectively. If the train departures are regular, that is, constant service time τ, then for long trains $f_{ij}(n)$ approaches a Poisson distribution with parameters $p_{ij}x_{\tau}$ where x is the total flow of cars through the yard and p_{ij} is the probability of a car being switched onto this classification track (track j with engine i), given in Equation 2.

It also is assumed in the above model that marshalling does not always change, with the same proportion of traffic in each block. Secondly, it is assumed that the service frequency is either (a) constant or (b) increases proportionally to the traffic. Constant service frequency implies that the size of the blocks pulled increases with the traffic through the yard. Service frequency proportional to traffic implies that the block size remains constant.

Even though this model results in a flexible analytical tool, it is criticized for the fact that it considers the basic units of arrival to the system to be trains, not individual cars, and thus Petersen (1977a,b) derives parameters for service time to classify an entire inbound train. It leads to some confusion about the relationship of the output process at one queue to the input for another.

C.4.2.3 Model 3

The model developed by Daughety and Turnquist (1979) recognizes the fact that the individual rail cars arrive in batches on trains. They use a more general batch arrival queueing model (compared to Petersen 1977a,b), given as

$M^x/G/1$: Poisson arrivals in batches of size x; arbitrary service time; and 1 server,

where x is a random variable corresponding to train length.

In this case Daughety and Turnquist report the average classification delay (time in queue plus service) as

$$T_C = \left[\frac{\rho}{2(1-\rho)}\left(\frac{\delta_2}{\delta_1} + \mu^2\sigma^2\right) + 1\right]/\mu , \qquad (12)$$

where δ_1 = average train length (cars),

δ_2 = second moment of train length,

$\rho = \bar{\lambda}\delta_1/\mu$ = traffic intensity of system,

$\bar{\lambda}$ = arrival rate of trains (trains/hr),

μ = average service rate (cars/hr), and

σ^2 = variance of service time distributions.

The distribution of service times for classifying cars depends greatly on the physical layout and operating plan of a particular yard and probably the most important distinction is between hump yards and flat yards.

Daughety and Turnquist observed a sample of flat switching operations in a yard and recorded the total time required and number of cars switched. For each of these observations, an equivalent "minutes/car" value was then computed. Finally, a gamma distribution was fit to these values. The probability density function of a gamma distribution with parameters α and β is

$$f(x) = \frac{\beta^{\alpha}}{T_{(\alpha)}} x^{a-1} e^{-\beta x} \qquad 0 \leqq x < \infty , \tag{13}$$

where α/β is the mean value of the gamma random variable x, and α/β^2 its variance. For the yard studies by Daughety and Turnquist it was found that α and β were 1.3 and 0.28, respectively. This gave the mean switching time as 4.6 minutes/car and a variance of 16.6 minutes^2/car. This estimate seemed to be well within the range of plausible values given by Wright (1960) and Martland and Rennicke (1978) of from 3 to 10 minutes/car for different levels of work load. The predicted delay by this model, for example (for the yard studied) is given as 8.2 hours, which is again within the plausible range of classification delay values reported by Folk (1972), Beckmann, et al. (1956) and Gentzel (1979) for various yards at different times. This range was found to be 4.6 to 22.4 hours.

The assembly delay has been derived as

$$T_a = \frac{S}{n} = \frac{\frac{k}{2}\int_0^{\infty} t^2 g(t)dt}{k\int_0^{\infty} t\, g(t)dt} = \frac{E(t^2)}{2E(t)} . \tag{14}$$

If desired, Equation 14 may be rewritten as

$$T_a = \frac{E(t)}{2} + \frac{\sigma_t^2}{2E(t)} , \tag{15}$$

where T_a = expected assembly delay and

$g(t)$ = probability density function ($0 < t < \infty$) of distribution of time intervals between successive outbound trains for a given block of cars.

In Equation 15, σ_t^2 is the variance in the time interval between successive departures. Note that if departures are completely regular ($\sigma_t^2 = 0$), the second term vanishes, and the expected delay is one-half the interval between trains (e.g., 12 hours for trains dispatched once per day). On the other hand, if dispatches occur very irregularly, the second term indicates that expected delay to cars will increase.

Equation 15 is analagous to a result widely used in studies of urban mass transit systems, expressing the mean waiting time of passengers at a bus stop. Derivations of the result in the mass transit context can be found in Welding (1963), Osuna and Newell (1972) or Kulash (1971).

The derivation of Equation 15 assumes that outbound train length is unlimited, or in queueing terms, that the batch size is infinite. In practical terms, this assumption is not really true, since there are limits to the length of train that can be dispatched. Such limits can be the result of mainline track configuration, power availability, etc. More sophisticated batch-service queueing models can be constructed to reflect these constraints, but for batch sizes in excess of 25-30, the numerical results are essentially the same as for infinite batch size (see Petersen [1971]). Since train length constraints would typically be well in excess of these values, use of a simpler, infinite-batch-size model is appropriate.

Thus, by obtaining the classification delay and the assembly delay from the two models described above, we can get the total delay each railroad car has in the yard.

C.5 LINE-HAUL COST MODELS

The purpose of the line-haul model is to reflect first the relationship between locomotive horsepower, trailing load, and velocity for a train; and second, the delays en route due to interactions among trains (meets, overtakes, etc.). Basically, interest is in the movement of trains. Here, also, two models are of interest: (1) for travel time and delay en route; and (2) for operating costs.

C.5.1 Models for Travel Time and Delay en Route

The various models available are described in the following subsections.

C.5.1.1 Model 1

This is the model described by Bronzini (1979a). In this model, the rail line-haul links have been divided into various classes as shown in Table C.4. Horsepower per trailing ton is a characteristic of the operating policy of the railroad that owns the link. Terrain and region in combination give a general indication of track layout and operating restrictions. Even though the exact influences of terrain and region are not known, they include grade, curvature, and speed limits.

Table C.4. Rail Line-Haul Link Classes[a]

	Region[b]					
	East		South		West	
Average Horsepower per Gross Trailing Ton[c]	Hilly Terrain	Flat or Rolling Terrain	Hilly Terrain	Flat or Rolling Terrain	Hilly Terrain	Flat or Rolling Terrain
3.0		EF130			WH130 WH230	WF130
2.5	EH125	EF125 EF225	SH125 SH225	SF125		WF125 WF225
2.0	EH120 EH220 EH320	EF120 EF220 EF320	SH120 SH220	SF120 SF220 SF320		WF120 WF220 WF320
1.7	EH117 EH217	EF117 EF217 EF317	SH117	SF117 SF217		WF117 WF217

From Bronzini (1979a).

[a] 5-digit class names shown in table are constructed as follows:

Digits	Symbol (Meaning)
1	E (East), S (South), W (West)
2	F (Flat), H (Hilly)
3	1 (single track), 2 (double track), 3 (3 or more tracks)
4,5	(HP per gross trailing ton) × 10

[b] Based on ICC regions East = Official, South = Southern, West = Western Trunk, Southwestern, and Mountain Pacific.

[c] Calculated from data reported in AAR Statistical Summary 57, "Statistics of the Railroads of Class I", Nov., 1973, assuming the average freight locomotive has a horsepower of 2500 hp.

These influences are captured by using the U.S. Department of Transportation's Transportation Systems Center (TSC) train performance calculator (TPC) over an actual route in the region-terrain class. The resulting free speeds have been given in Table C.5.

Table C.5. Rail Link Free Speed Travel Rates

Horsepower per Trailing Ton	East Region		South Region[a]		West Region	
	Hilly Terrain	Flat Terrain	Hilly Terrain	Flat Terrain	Hilly Terrain	Flat Terrain
3.0	0.024/C	0.023/B	0.029/D	0.025/C	0.022/B	0.019/A
2.5	0.025/C	0.023/B	0.029/D	0.026/C	STALLED	0.019/A
2.0	0.027/C	0.023/B	0.031/D	0.026/C	STALLED	0.020/A
1.7	0.029/D	0.024/C	0.033/D	0.027/C	STALLED	0.020/A
Representative route (round trip)	Allentown to Buffalo	Weehauken to Buffalo via Selkirk	see note	see note	Los Angeles to N. Platte via Salt Lake City	Topeka to Tucumcari

From Bronzini (1979a, p. 20).

[a]Since no track charts were accessible, free speed in the south was calculated from those of the East and West using the formula

$$S_s = \tfrac{1}{2} \quad \frac{S_E A_S}{A_E} + \frac{S_W A_S}{A_W},$$

where S_i = speed by region (S = South, E = East, W = West),

A_i = AAR reported average speed by region,

A_E = 17.4 mph or 0.057 hr/mi,

A_S = 16.5 mph or 0.061 hr/mi, and

A_W = 23.5 mph or 0.043 hr/mi.

The free speed calculated by the TPC is used in a train delay model to produce estimates of delay due to congestion as a function of the number of trains on the links (Fig. C.2). (The train delay model, program and documentation, is given in Bronzini 1979b, pp. 189-193.) Delay and free speed (see Table C.5) can be combined to produce an estimate of effective speed over the link. The sets of single-track delay functions developed for these three regions are presented in Figures C.3, C.4, and C.5. (The number of trains on a link per day can be converted to net kilotons per year with a constant that reflects the average net tons per train.)

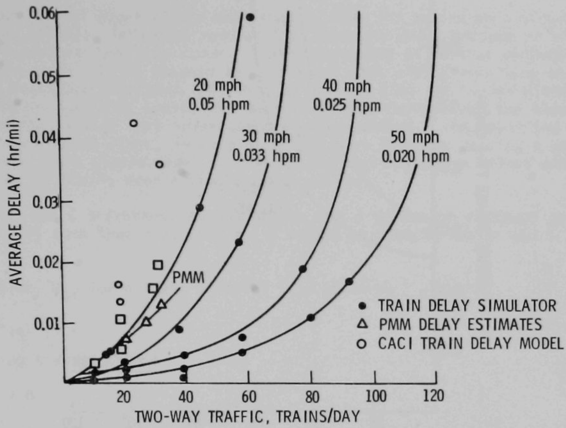

Fig. C.2. Single Track Train Delay Functions.
Redrawn from Bronzini (1979a, p. 22).

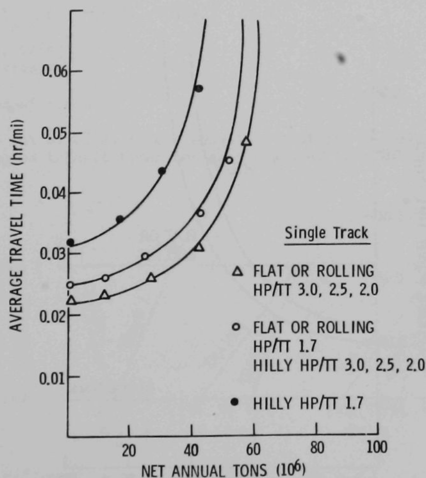

Fig. C.3. Eastern Region Rail Time Functions.
Redrawn from Bronzini (1979a, p. 23).

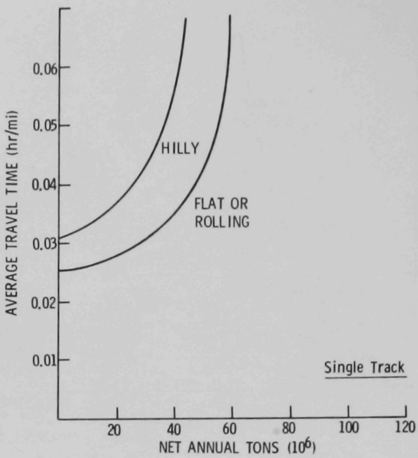

Fig. C.4. Southern Region Rail Time Functions. Redrawn from Bronzini (1979a, p. 24).

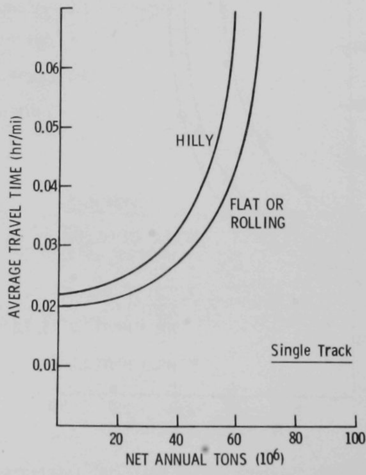

Fig. C.5. Western Region Rail Time Functions. Redrawn from Bronzini (1979a, p. 25).

C.5.1.2 Model 2

Model 2 is a simple analytical model of the mean running time for trains on a single track railway, given by Petersen (1974). This mean running time includes delay because of train priority schemes, meets, and overtakes that may occur. Trains operating at several different speeds in each direction are permitted. It is assumed in this model that sidings are long enough to accommodate the resulting meets and overtakes. It is also assumed that the trains within each class (priority system based on speed of train) are uniformly distributed over the time period of interest and the distributions of each speed class are independent. The resulting mean running times for trains in each speed class, in each direction, are found by solving a set of linear equations. This results in a simple model for estimating the congestion delays and interaction between different types of trains over a single track section.

Consider an index set for I different inbound speeds and J different outbound speeds $k = \{-I,-I+1,... -1,1,2,...J\}$ such that $i \varepsilon k$, then $i < 0$ refers to inbound trains and $i > 0$ refers to outbound trains.

The average transit time, W_i, for a train at speed i is given by

$$W_i = T_i + \Sigma_{j\varepsilon k} D_{ij} M_{ij} , \tag{16}$$

where T_i = free running transit time

$$= \begin{cases} d/s_i & i > 0 \\ -d/s_i & i < 0 \end{cases} \tag{16a}$$

for two yards connected by a single track railway at a distance d apart. Let s_i be the free running speed and

M_{ij} = the number of encounters (meets or overtakes) by a single train of type i with all trains of type j on its trip between yards.

D_{ij} = Constant delay incurred by train i, whenever a train at speed i encounters a train at speed j.

Peterson, after considering the three cases of interferences shown in Figure C.6, calculates the expected number of interferences and concludes that

$$W_i = d/v_i = d/s_i + \Sigma_{j\varepsilon k} E_{ij} N_j(d/v_i - d/v_j) , \tag{17}$$

$$\text{where } E_{ij} = \begin{cases} -D_{ij} & j<i<0,\ 0<i<j \\ D_{ij} & \text{otherwise} \end{cases} \tag{18}$$

v_i = average speed of train i.

This equation gives us a set of (I+J) linear equations that can be solved for the (I+J) variables d/v_i, which are the expected transit times for each class of train.

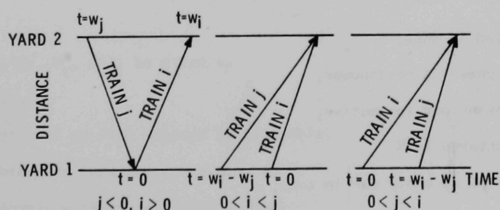

Fig. C.6. Number of Interferences. Redrawn from Petersen (1974).

An expression may be derived for the expected delay, D_{ij}, to train i, when it encounters an interference with train j. Petersen considers three cases of interference delay, as shown in Figure C.7. The lower-case delta in Figure C.7 refers to the distance from the projected interference point to the siding where the meet or overtake actually occurs. The expression derived is

$$D_{ij} = s_i + \frac{p_{ij}^2}{2(\ell+1)} \; d/s_i - d/s_j \qquad \text{for } i > 0 \quad , \tag{19}$$

where s_i = the required switching time for train i,

ℓ = the number of equally (assumed) spaced sidings, and

p_{ij} = the relative amount of time that train i waits for train j.

One of the limitations of the model is that by assuming a constant delay, for all interferences, it is implicitly assumed that the meets and overtakes that occur involve only two trains and multiple train interactions are handled two trains at a time. Thus, the above model can best be described as a low-density traffic model.

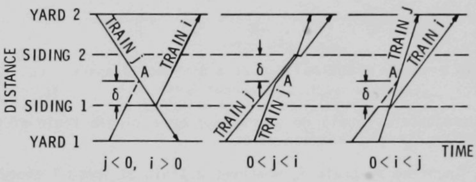

Fig. C.7. Interference Delays. Redrawn from Petersen (1974).

C.5.1.3 Model 3

Model 3 is given by Daughety and Turnquist (1979). The schematic illustration of the model is given in Figure C.8.

Suppose that the mean free speed of the train is V (miles per hour), which takes into account the track profile in-between two stations; then the model gives the following equation:

$$TL = \frac{309HP/V-(65.6n+0.96Vn+0.29V^2+640Sn)}{37.6(W_e^{\frac{1}{2}}+W_f^{\frac{1}{2}})+0.1\delta V(W_e+W_f)+0.087V^2+80S(W_e+W_f)+100} \; 4(W_eW_f) \;, \tag{20}$$

where TL = trailing load in tons,

HP = locomotive power in horsepower,

n = number of axles per locomotive,

S = grade encountered in %,

W_e = axle weight of an empty car in tons,

W_f = axle weight of a full car in tons, and

V = mean free speed of the train in mph without delay (due to meets and overtakes).

Figure C.3

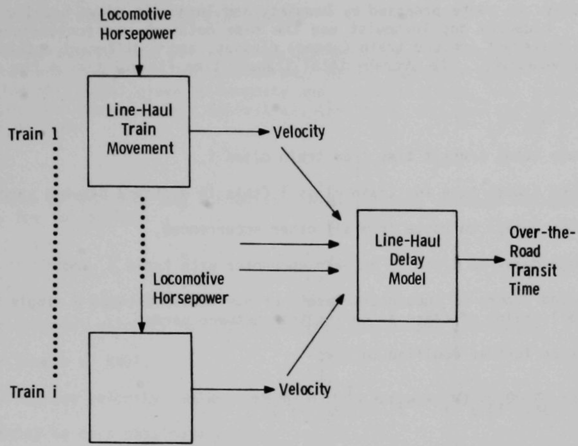

Fig. C.8. Schematic Illustration of Model 3

Daughety and Turnquist have used standard values of $W_e = 7$ and $W_f = 19.5$ in the above equation, but other values of W_e and W_f may be substituted, depending on the policy on which tonnage ratings are based. To use this model, to obtain V, first find the ruling gradient and some assumed speed V. For example, in the track profile given in Figure C.9, Section 2-3 is chosen as the ruling gradient, and the required locomotive power for some speed V is found. Once the available locomotive power is known, the speed for the remaining sections of the track profile can be found.

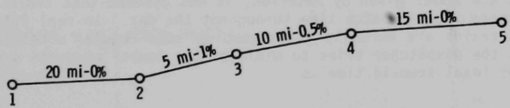

Fig. C.9. Typical Track Profile

Figure C.9

Then the expected velocity, V_a, will be given as

$$V_a = \min[V_t, V_g, V_{TL}] ,$$

where V_t = speed restriction on line imposed by timetable,

V_g = maximum achievable locomotive speed, and

V_{TL} = speed attainable with given trailing load.

Once the free expected velocity of train V_a is known, the delay due to meets and overtakes by other trains en route can then be found.

The model for delays en route proposed by Daughety and Turnquist draws heavily on work done by Petersen (1974). Daughety and Turnquist use the same notation and conventions, as used by Petersen, with K different inbound train (speed) classes, and L different outbound classes (outbound speeds are negative). The average total transit time (travel time + the delays) is given as follows:

$$W_i = R_i \; S_i + \sum_j D_{ij} \; M_{ij} \quad , \tag{21}$$

where W_i = average total transit time from train class i,

R_i = average travel time for train class i (this is distance between yards/V_a),

S_i = average delays en route from all other occurrences,

D_{ij} = average delay to train i, on each encounter with train j, and

M_{ij} = expected number of encounters (meets or overtakes) between a single train of class i and all trains of class j, on its trip between yards.

This equation may be further modified to give

$$W_i = R_i + S_i + \sum_{j \varepsilon I} D_{ij} N_j (W_i + W_j) + \sum_{j \varepsilon O_S} D_{ij} N_j (W_j - W_i) + \sum_{j \varepsilon O_f} D_{ij} N_j (W_i - W_j) \quad , \tag{22}$$

where N_j = rate of dispatching of train class j (trains/unit time),

O_S = set of outbound train classes of lower speed than i, and

O_f = set of outbound train classes of higher speed than train i.

This gives K+L simultaneous linear equations that can be solved for K+L unknowns, W_i. If the line under study is double track then the term delay due to meets $\sum_{j \varepsilon I} D_{ij} N_j (W_i + W_j)$ will vanish. This model is similar to Petersen's work, but it has been modified by English (1977) so that it can reflect operations on high-density line more accurately. These modifications account for multiple meets and delays induced by signal systems in very high-density operations. In the modification of the above model, a more general expression for M_{ij} is sought.

In the above model and the model given by Petersen, it was assumed that trains are dispatched randomly with constant mean interdispatch time throughout the day. In real life, this generally is not true. In fact, trains are normally dispatched at some regular schedule and line-haul delay might be less, as the dispatcher tries to minimize the number of meets and overtakes. The modified model gives the total transit time as

$$W_i = R_i + S_i + \sum_j D_{ij} \sum_{x=1}^{\infty} p[xk, (W_i + W_j)] \quad , \tag{23}$$

where x = number of dispatches in a period of length W,

$$W = \frac{(W_i + W_j)}{\lambda} \quad ,$$

λ and k are the parameters of Erlang-k distribution that fits the interdispatch time of trains,

λ = average rate of dispatching (= 1/mean time between trains), and

p is a distribution function given as $p(z,t) = \sum_{i=z}^{\infty} \frac{e^{-t} t^i}{i!}$. (24)

This equation also gives us a set of (K+L) non-linear equations in the (K+L) unknowns, W_I. They can be used to provide a more general solution for line-haul delays.

C.6 OPERATING COST MODEL FOR YARDS AND LINE-HAULS

In this section, those models that will give the operating cost for railroads in terms of dollars, both for yards and line-hauls are considered. Before any other model is discussed, there will be a discussion of a model given by Daughety and Turnquist (1979) that gives the operating cost, which includes the costs of yard activities, line-haul, and even the yard and line-haul delays in terms of dollars.

C.6.1 Model 1

Model 1 was developed by Daughety and Turnquist (1979). First, average shipment velocity is estimated given by the following:

$$\bar{V} = \frac{L}{\frac{L}{V_a} + T_y} = \frac{LV_a}{L + T_y V_a} , \tag{25}$$

where $\bar{V}$ = average shipment velocity through the system (yards and line-haul),

L = average length of haul,

V_a = overall average velocity, aggregated over track segments (line-haul), and

T_y = total delay to cars passing a yard.

In Equation 25, it is assumed that each shipment passes through one classification yard. If a shipment passes through more than one classification yard, T_y must be the sum of the delays in passing through various yards. Moreover, L/V_a must be the sum of the transit times over different line segments, rather than one aggregate time.

The cost model is as follows:

$$\begin{aligned} C = {} & \alpha_0 + \alpha_{10}\,PCAR + \alpha_{20}\,PFUEL + \alpha_{30}\,PCREW + \alpha_{40}\,PLOCO + \alpha_{50}\,PMNGT + \beta_{10}\,Y + \gamma_{10}\,S + \delta_{10}\,QK \\ & + \tfrac{1}{2}\alpha_{11}\,(PCAR)^2 + \alpha_{12}\,PCAR\cdot PFUEL + \alpha_{13}\,PCAR\cdot PCREW + \alpha_{14}\,PCAR\cdot PLOCO + \alpha_{15}\,PCAR\cdot PMNGT \\ & + \tfrac{1}{2}\alpha_{22}\,(PFUEL)^2 + \alpha_{23}\,PFUEL\cdot PCREW + \alpha_{24}\,PFUEL\cdot PLOCO + \alpha_{25}\,PFUEL\cdot PMNGT \\ & + \tfrac{1}{2}\alpha_{33}\,(PCREW)^2 + \alpha_{34}\,PCREW\cdot PLOCO + \alpha_{35}\,PCREW\cdot PMNGT \\ & + \tfrac{1}{2}\alpha_{44}\,(PLOCO)^2 + \alpha_{45}\,PLOCO\cdot PMNGT \\ & + \tfrac{1}{2}\alpha_{55}\,(PMNGT)^2 \\ & + \tfrac{1}{2}\beta_{11}(Y)^2 + \tfrac{1}{2}\gamma_{11}(S)^2 + \tfrac{1}{2}\tau_{11}Y\cdot S \\ & + \theta_{11}\,PCAR\cdot Y + \theta_{21}\,PFUEL\cdot Y + \theta_{31}\,PCREW\cdot Y + \theta_{41}\,PLOCO\cdot Y + \theta_{51}\,PMNGT\cdot Y \\ & + \sigma_{11}\,PCAR\cdot S + \sigma_{21}\,PFUELS\cdot S + \sigma_{31}\,PCREW\cdot S + \sigma_{41}\,PLOCO\cdot S + \sigma_{51}\,PMNGT\cdot S \\ & + \delta_{11}(QK)^2 + \mu_{11}QK\cdot Y + \varepsilon_{11}QK\cdot S \\ & + \eta_{11}\,PCAR\cdot QK + \eta_{21}\,PFUEL\cdot QK\ \eta_{31}\,PCREW\cdot QK + \eta_{41}\,PLOCO\cdot QK + \eta_{51}\,PMNGT\cdot QK , \end{aligned} \tag{26}$$

where C = ℓn (cost/average cost),

PCAR = ℓn (price of cars/average price of cars),

PFUEL = ℓn (price of fuel/average price of fuel),

PCREW = ℓn (price of crews/average price of crews),

PLOCO = ℓn (price of locos/average price of locos),

PMNGT = ℓn (price of non-crews/average price of non-crews),

Y = ℓn (loaded car-miles/average loaded car-miles),

S = ℓn (speed/average speed), and

QK = ℓn (FRA category four percentage/average FRA category four percentage).

There are 5 prices, 2 outputs, and 1 fixed factor, resulting in 45 coefficients to be computed.

As will be observed from the cost function description, all variables are divided by their means, i.e., an observation is divided by the mean of the observations before taking the logarithm. This is done mainly to protect the proprietary nature of the data. By so transforming the variables, only the intercept term is affected, leaving the important coefficients undisturbed. This way, actual costs for the railroad under study are predictable only by those with a proprietary interest while cost relationships are open to perusal by all. In view of this, the variable means have not been published since they add nothing to an understanding of the cost functions, and only reveal proprietary information. The estimated cost function is given in Table C.6.

C.6.2 Model 2

Model 2 was given by Bronzini (1979a). The model presents different models for yard and line-haul operating costs. Different models have been given for different regions: East, South, and West.

C.6.2.1 Yard Operating Cost Model

The yard operation cost consists of node cost and the energy use cost. The node cost has been given as the sum of the capital cost of idle railcars plus the switching cost. Idle railcar cost is

$$RCC = (CC \times IT \times (1 + FEB_R)/NET_R) \times 1000 \quad , \tag{27}$$

where RCC = railcar capital cost per kiloton,

CC = average railcar capital cost per hour,

IT = idle time per node,

FEB_R = fraction of freight movements that result in an empty back-haul in region R, and

NET_R = average net tons per loaded car in region R.

Data to calculate idle railcar cost per node for each region, along with the calculated cost, are presented in Table C.7.

The switching cost is given as

$$SC = (SM_R \times CPSM \times (1 + FEB_R)/NET_R) \times 1000 \quad , \tag{28}$$

where SC = switching cost per 10^3 ton per node,

SM_R = switch minutes per car per node in region R,

$CPSM$ = cost per switch minute,

and FEB_R and NET_R are previously defined and reported in Table C.7.

Deboer (1974) reports the average distance between yards as 200 miles. This fact, the average trip length, and number of nodes (yards) per trip, along with the assumption that two interchange switches occur for every intertrain or intratrain switch (Table C.8), give the regional switch minutes per car per node and switch cost per 10^3 ton per node.

The yard (node) energy consumption is given as

$$SE_R = (GPM \times SM_R \, (1 + FEB_R)/NET_R) \times 1000 \quad , \tag{29}$$

where SE_R = switch energy (gallons per 10^3 ton) per node in region R,

GPM = switch engine fuel consumption (gallons per switch minute),

and SM_R, FEB_R and NET_R are the same as defined above.

Table C.6. Cost Functions

Variable	Coefficient	Estimate	Std. Error
--	α_0	0.03997	0.01123
PCAR	α_{10}	0.31748	0.00494
PFUEL	α_{20}	0.04767	0.00086
PCREW	α_{30}	0.15185	0.00130
PLOCO	α_{40}	0.08354	0.00084
PMNGT	α_{50}	0.39945	0.00300
QK	δ_{10}	-0.92323	0.13530
Y	β_{10}	0.08939	0.07851
S	γ_{10}	-0.04843	0.05306
$(PCAR)^2$	α_{11}	-0.02637	0.02267
PCAR·PFUEL	α_{12}	0.00526	0.00628
PCAR·PCREW	α_{13}	0.00216	0.00766
PCAR·PLOCO	α_{14}	0.04086	0.00765
PCAR·PMNGT	α_{15}	-0.02167	0.01535
$(PFUEL)^2$	α_{22}	0.05928	0.01022
PFUEL·PCREW	α_{23}	-0.01716	0.00835
PFUEL·PLOCO	α_{24}	-0.02293	0.00706
PFUEL·PMNGT	α_{25}	-0.02422	0.00133
$(PCREW)^2$	α_{33}	0.10596	0.01404
PCREW·PLOCO	α_{34}	-0.01861	0.00729
PCREW·PMNGT	α_{35}	-0.07234	0.01491
$(PLOCO)^2$	α_{44}	0.03863	0.00936
PLOCO·PMNGT	α_{45}	-0.03794	0.01019
$(PMNGT)^2$	α_{55}	0.15617	0.02461
$(Y)^2$	β_{11}	0.23904	0.49667
$(S)^2$	γ_{11}	-0.07679	0.14596
Y·S	τ_{11}	-0.21683	0.20978
PCAR·Y	θ_{11}	0.024151	0.04496
PFUEL·Y	θ_{21}	0.00451	0.00800
PCREW·Y	θ_{31}	0.01064	0.01191
PLOCO·Y	θ_{41}	-0.01131	0.00777
PMNGT·Y	θ_{51}	-0.02800	0.02758
PCAR·S	σ_{21}	0.01480	0.01839
PFUEL·S	σ_{22}	-0.00463	0.00324
PCREW·S	σ_{23}	-0.00381	0.00487
PLOCO·S	σ_{24}	0.00367	0.00319
PMNGT·S	σ_{25}	-0.01004	0.01120
$(QK)^2$	δ_{11}	-12.84350	3.36250
QK·Y	μ_{11}	0.81675	0.78897
QK·S	ε_{11}	-0.00451	0.28319
PCAR·QK	η_{11}	-0.21474	0.08022
PFUEL·QK	η_{21}	0.02840	0.01436
PCREW·QK	η_{31}	0.05061	0.02123
PLOCO·QK	η_{41}	0.00755	0.01399
PMNGT·QK	η_{51}	0.12819	0.04957

Table C.7. Idle Railcar Cost

Region	Railcar Capital Cost ($/hr)[a]	Idle Time per Node (hr)	Fraction Empty Return[b]	Net Tons per Loaded Car[c]	Railcar Capital Cost per 10^3 Ton per Node
East	0.246	12.3	0.768	54.6	$97.98
South	0.246	12.3	0.832	59.3	$93.48
West	0.246	12.3	0.748	56.0	$94.45

From Bronzini (1979a).

[a]Calculated from 1970 costs presented in Railway Age, Nov. 29, 1976, p. 3; an inflator based on the Association of American Railroad index of prices for materials and supplies other than fuel; and a capital recovery factor based on a 20-yr life, 10% salvage value, and a 10% interest rate.

[b]Calculated from percent of total freight car miles loaded reported by the Association of American Railroads (1972).

[c]Reported in Association of American Railroads (1980, p. 40).

Table C.8. Switch Cost per Node by Region

Region	Interchange Switch Time per Car (min)	Intertrain and Intratrain Switch Time per Car (min)[a]	Avg. Switch Time per Node per Car (min)	Cost per Switch Min ($)[b]	Switch Cost per 10^3 Ton per Node
East	13.9	4.0	3.5	0.98	$112.05
South	12.6	2.9	3.2	0.98	$ 95.45
West	14.1	3.2	3.7	0.98	$111.87

From Bronzini (1979a).

[a]From Interstate Commerce Commission (1975, pp. 138, 140).

[b]From Murphy (1976, p. 76).

Murphy (1976) reports that switch engine fuel consumption is 10 gallons per hour. Fuel consumption per node is presented in Table C.9 along with the node cost (idle railroad car cost + switching cost).

So, to calculate the energy cost, the present price of energy ($/gal) is multiplied by the energy consumed. Bronzini (1979a) further multiplies these costs by what is known as rail node commodity factors, because the average net tons per loaded car, the ratio of empty to loaded car miles, and the average railcar cost vary depending on the commodity shipped. Table C.9 contains the standard costs and energy consumed, which should be multiplied by the commodity adjustment factors given in Table C.10.

Table C.9. Railroad Node Cost and Energy per Region

Region	Cost ($/$10^3$ ton)	Energy	
		gal/10^3 ton	Btu/ton[a]
East	210.03	18.89	2620
South	188.93	16.48	2285
West	206.32	19.25	2670

From Bronzini (1979a).

[a]1 gal = 138,690 Btu.

In the Bronzini model also, the interchange switch time per car, intertrain and intratrain switch time per car, and average switch per node per car all are constant for a given region and are shown independent of node (yard) characteristics, which is not true. Moreover, it is not clear how they have been derived.

Table C.10. Commodity Adjustment Factors

Commodity	STCC	Net Tons Per Loaded Car[a]	Fraction Empty Return[b]	Average Railcar Capital Cost/Hr[c]	Adjustment Factor		
					Time	Cost	Energy
Field crops	01	70.6	0.90	0.217	1.0	0.85	.85
Forestry & fishery products	08,09	--	--	--	--	--	--
Metallic ores	10	80.7	0.95	0.208	1.0	0.77	0.77
Coal[d]	11	77.3	0.91	0.185	0.5	0.53	0.53
Crude petroleum	13	55.1	1.07	0.293	1.0	1.19	1.19
Nonmetallic minerals	14	75.2	0.93	0.203	1.0	0.81	0.81
Food & kindred products	20	46.2	0.88	0.230	1.0	1.29	1.29
Textiles & apparel	22,23	19.7	0.69	0.199	1.0	2.72	2.72
Lumber & furniture	24,25	49.0	0.86	0.216	1.0	1.21	1.21
Pulp, paper & allied products	26	37.8	0.71	0.195	1.0	1.44	1.44
Chemicals	28	65.2	0.99	0.254	1.0	0.97	0.97
Petroleum & coal products	29	70.0	1.00	0.211	1.0	0.91	0.91
Primary metal products	33	63.6	0.82	0.206	1.0	0.91	0.91
Fabricated metal products	34	34.4	0.81	0.205	1.0	1.67	1.67
Nonelectrical machinery	35	23.5	0.69	0.213	1.0	2.28	2.28
Electrical machinery	36	16.1	0.70	0.201	1.0	3.35	3.35
Transport equipment	37	23.2	0.70	0.206	1.0	2.33	2.33
Misc. manufactured		64.9	0.91	0.212	1.0	0.93	0.93
TOFC[e]		30.6	0.45	0.310	1.0	1.30	1.46

From Bronzini (1979a).

[a]Calculated from average tons per car by railroad car type and commodity, 1972, Table B-2, and percent of tons moving on each railroad car type by commodity, 1972, Table B-5, in Peat, Marwick, Mitchell & Co. (1976).

[b]Calculated from the ratio of empty to loaded freight car miles by railcar type in Table B-6 and the percent of tons moving on each railroad car type by commodity, 1972, Table B-5, in Peat, Marwick, Mitchell & Co. (1976).

[c]Calculated: the percent of tons moving on each railroad car type by commodity, 1972, Table B-5, Peat, Marwick, Mitchell & Co. (1976); 1970 railroad car costs reported in Railway Age, Nov. 29, 1976, pp. 3; an inflator based on the Association of American Railroads index of prices for material and supplies other than fuel, and a capital recovery factor based on a 20-year life, 10% salvage value and a 10% interest rate.

[d]One-third of the coal volume is assumed to be shipped in unit trains which do not experience node interchange or intratrain switching, or intermediate yard delay.

[e]Data on TOFC are taken from Reebie Associates (1972), pp. 70.

C.6.2.2 Line-Haul Operating Cost Model

The model is based upon determination of the cost of rail transportation over a particular rail segment, which is defined as a mainline route with no intervening terminals or major functions. The approach used is "engineered economic costs," in which the resources required to provide rail transport are determined using engineering relationships and resource "prices" including both capital and operating expenses to determine the costs incurred.

The following cost elements are included in the model:

- Line-haul facility
- Locomotive
- Crew
- Fuel
- Railcar
- Overhead

Rail line-haul cost functions are based on fuel consumption and effective speed functions given in Section 5.1.1, and on train and operating characteristics. The model is basically a modified version of the TSC model described in Murphy (1976). Modifications made by Bronzini (1979a) include removal of costing elements related to rail terminals, introduction of travel time and fuel consumption as functions of annual tonnage, and generation of a complete cost vs. tonnage function in a single run of the model.

The train and operating data used to generate the costs given in Bronzini (1979a, p. 29) are given in Table C.11. Cost functions for the major line-haul link classes are given in Figures C.10-C.14.

The fuel consumption for the line-haul is calculated as a function of net annual tonnage. The variables that give the fuel consumption are: the fuel consumption on the route produced by the TPC; the idling fuel consumption; and the delay/mile as a function of net annual tons. The idling fuel consumption by locomotives is given in Murphy (1976). Delay-caused fuel consumption is given by:

$$DF_{LC} = (NT \times G/N_R \times HP/TT_{LC}/3000)6 \ , \qquad (30)$$

where DF_{LC} = delay fuel consumption in gal/train-hour for link class LC,

NT_R = net tons per train in region R,

G/N_R = gross trailing ton to net ton ratio for region R,

HP/TT_{LC} = horsepower per gross trailing ton for link class LC,

3000 = horsepower/locomotive (GP-40), and

6 = idling fuel consumption of a GP-40 in gal/hr.

These functions are given in Table C.12.

As in the case of yards, commodities differ substantially with regard to the average attributes influencing cost. Average net tons per car, average car tare weight, car cost and fraction empty backhaul combine to produce commodity-specific line-haul adjustment factors. Table C.13 contains this information along with the line-haul link adjustment factors.

Table C.11. Sample Rail Line-Haul Cost Data

Train	
Horsepower/trailing ton	3.0
Number of loaded cars	35.30
Number of empty cars	0.0
Fraction of empty backhaul	0.768
Interest rate	0.100
Roadway 1 track	
Welded (1) or jointed (2)	2.
K1-inspection	0.830
K2-rails	0.830
K3-ties	0.830
K4-surfacing	0.830
Investment, ¢ per gross trailing ton	0.023
Investment life (year)	25
Locomotive	
Maintenance/mile	0.55
Horsepower/locomotive	3,000
Locomotive weight (ton)	133
Value/locomotive ($)	360,000
Salvage (fraction)	0.100
Locomotive life (year)	15
Annual hours utilization	3,482
Railcar	
Tare weight (ton)	30.2
Maintenance/mile ($)	0.032
Value/car ($)	18,661
Salvage (fraction)	0.100
Railcar life (year)	20
Annual hours utilization	8,760
Net tons/loaded car	54.6
Miscellaneous	
Crew cost/mile ($)	2.72
Fuel cost/gallon ($)	0.12
Helper locomotive, mills/ton-mile	0.0
Inflator/deflator from 1972	1.00
Factor to convert to gallons	0.460
Misc. costs (¢/gross trailing ton-mile)	0.740

From Bronzini (1979a).

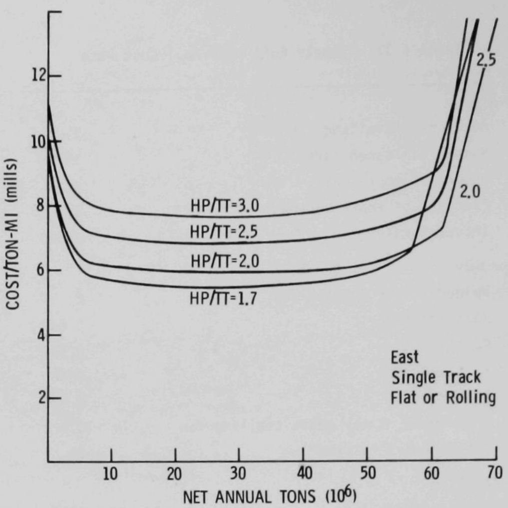

Fig. C.10. Rail Line-Haul Link Cost Functions, East. Redrawn from Bronzini (1979a).

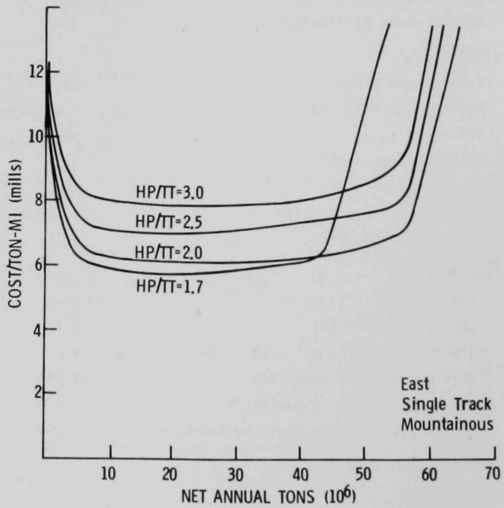

Fig. C.11. Rail Line-Haul Link Cost Functions, East. Redrawn from Bronzini (1979a).

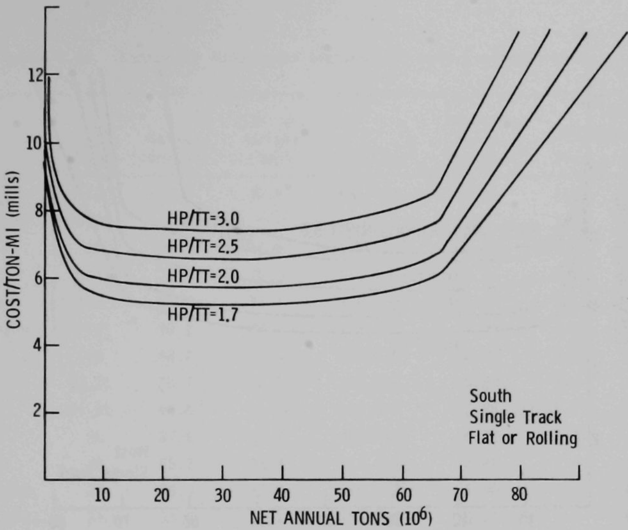

Fig. C.12. Rail Line-Haul Link Cost Functions, South. Redrawn from Bronzini (1979a).

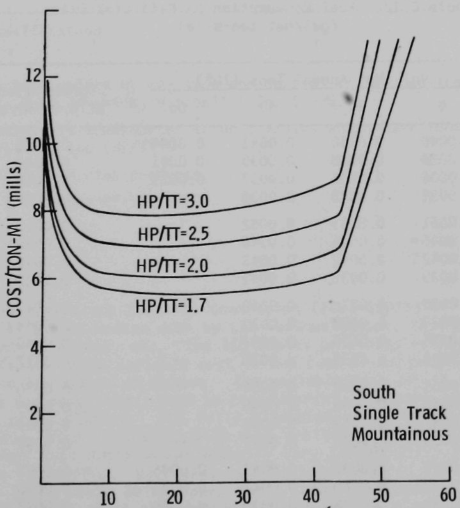

Fig. C.13. Rail Line-Haul Link Cost Functions, South. Redrawn from Bronzini (1979a).

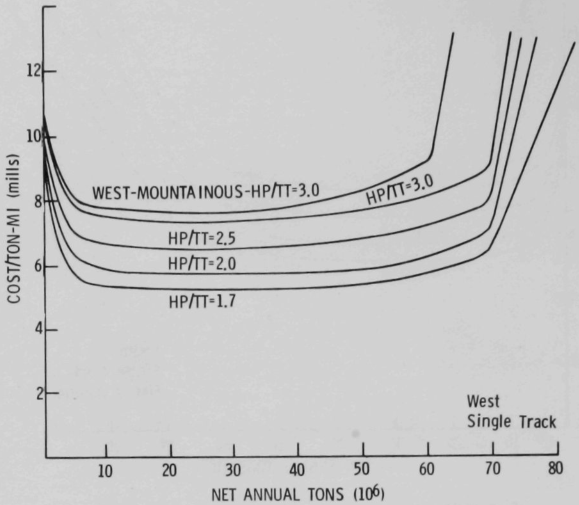

Fig. C.14. Rail Line-Haul Cost Link Functions, West. Redrawn from Bronzini (1979a).

Table C.12. Fuel Consumption by Rail Link Class (gal/net ton-mile)

Link Class	Vol. Net Annual Tons (10^6) 0	20	40	60	Consumption at 0.07 hr/mi	Vol.
EF130	0.0040	0.0040	0.0041	0.0044	0.0046	62
EF125	0.0038	0.0038	0.0039	0.0041	0.0043	62
EF120	0.0036	0.0036	0.0037	0.0039	0.0040	62
EF117	0.0035	0.0035	0.0036	--	0.0038	57
EH130	0.0051	0.0051	0.0052	--	0.0057	57
EH125	0.0045	0.0045	0.0046	--	0.0050	57
EH120	0.0042	0.0042	0.0043	--	0.0046	57
EH117	0.0039	0.0039	0.0041	--	0.0042	45
SF130	0.0039	0.0039	0.0040	--	0.0047	59
SF125	0.0038	0.0038	0.0039	--	0.0043	59
SF120	0.0036	0.0036	0.0037	--	0.0040	59
SF117	0.0034	0.0034	0.0035	--	0.0037	59
SH130	0.0051	0.0052	0.0054	--	0.0056	45
SH125	0.0045	0.0046	0.0048	--	0.0049	45
SH120	0.0041	0.0042	0.0043	--	0.0044	45
SH117	0.0039	0.0039	0.0041	--	0.0042	45
WF130	0.0042	0.0042	0.0043	0.0045	0.0049	70
WF125	0.0040	0.0040	0.0041	0.0043	0.0046	70
WF120	0.0038	0.0038	0.0039	0.0040	0.0043	70
WF117	0.0037	0.0037	0.0038	0.0039	0.0041	70
WH130	0.0054	0.0054	0.0056	0.0060	0.0061	61

From Bronzini (1979a).

Table C.13. Commodity Adjustment Factors for Rail Line-Haul Links

Commodity	SIC[a] Code	Net Wt. (ton/car)[b]	Car Tare Weight (ton)[c]	Car Cost[b]	Fraction Empty Backhaul[b]	Commodity Adjustment Factors		
						Time	Cost	Energy
Field crops	01	70.6	30.4	$16,458	0.90	1.0	0.94	0.92
Forestry & fishery	08,09	--	--	--	--	1.0	1.0	1.0
Metallic ores	10	80.7	28.8	$15,719	0.95	1.0	0.89	0.84
Coal[d]	11	77.3	26.1	$13,981	0.91	1.02	0.75	0.70
Crude petroleum	13	55.1	31.1	$22,198	1.07	1.0	1.16	1.10
Nonmetallic minerals	14	75.2	28.0	$15,358	0.93	1.0	0.91	0.87
Food & kindred	20	46.2	32.6	$17.418	0.88	1.0	1.16	1.18
Textiles & apparel	22,23	19.7	32.2	$15,036	0.69	1.0	1.65	1.90
Lumber & furn.	24,25	49.0	31.3	$16,357	0.86	1.0	1.11	1.11
Paper & allied	26	37.8	30.7	$14.745	0.71	1.0	1.19	1.21
Chemicals	28	65.2	31.2	$19,211	0.99	1.0	1.03	0.99
Petro. & coal prod.	29	70.0	27.0	$16,000	1.00	1.0	0.96	0.90
Primary metals prod.	33	63.6	31.1	$15,558	0.82	1.0	0.95	0.96
Fab. metals	34	34.4	31.3	$15,532	0.81	1.0	1.33	1.34
Non-elect. machinery	35	23.5	35.4	$16,128	0.69	1.0	1.70	1.79
Elect. machinery	36	16.1	32.6	$15,228	0.70	1.0	2.18	2.25
Transport equipment	37	23.2	33.3	$15,618	0.70	1.0	1.68	1.74
Misc. manuf.[e]		64.9	30.2	$16,087	0.91	1.0	0.97	0.95
TOFC[f]		30.4	46.1	$23,483	0.45	1.0	2.03	2.93

[a] Standard Industrial Classification.

[b] From Bronzini (1979a).

[c] Calculated from average tare weight by car type and percent of tons moving on each railroad car type by commodity, 1972, Peat, Marwick, Mitchell & Co. (1976).

[d] One-third of the coal volume is transported in unit trains which have four locomotives and 70% lower horsepower per trailing ton (HP/TT).

[e] Predominantly stone, glass, and clay products.

[f] TOFC is assumed to use 1/3 higher HP/TT.

C.6.3 Model 3

Model 3 is given by the Interstate Commerce Commission (ICC) (1975) for railroad. The ICC models are in the form of tables broken down by the various factors that are taken into account, such as shipment, weight, distance, etc. The ICC tables or models estimate two types of cost: variable and fully allocated. The variable cost is the same as defined in classical economics, the cost that depends on the amount of output. The variable cost in ICC models is the same but with liberal allowances for many items, such as car-ownership, to vary, so that they represent a relatively long period of adaptation. The fully allocated costs include allocations of all costs incurred to various units of traffic with much arbitrary allocation of some costs, since it is unclear exactly how such costs would actually vary (if at all except over a very long period) with variations in traffic. Railroads pay the total cost of their tracks, etc., in the form of an essentially fixed cost, which makes their total cost appear quite different with respect to the fraction of all costs that are fixed. If someone else owned the rail lines and charged on the basis of use, then these costs would become variable. We would be interested in variable cost per shipment, compared to the fully allocated cost, for our use. The variable cost includes both the yard and line-haul operating costs.

Morlok (1978) developed equations for variable costs as close approximates to ICC tables. For a standard boxcar (in ICC jargon, Boxcar, general services, unequipped), moving in the official territory (the northeastern and midwestern states), the variable cost is given as

$$VC_R = [116 + 0.00036S + L(0.31735 + 0.0001482S) + (36.54I - 0.06669L) + (12.04Y - 0.06017L)] \quad (31)$$

$$FAC_R = [116 + 0.02446S + L(0.31735 + 0.0002861S)] + (36.54I - 0.6669L) + (12.04Y - 0.06017L) \quad , \quad (32)$$

where VC_R = rail variable cost per shipment ($),

FAC_R = rail fully allocated cost per shipment ($),

S = shipment weight (cwt),

L = actual length of haul (mi),

I = number of railroad to railroad interchanges, and

Y = number of intermediate (not two end points) switching in yards.

In Equation 31 the first part is the line-haul cost:

$$\text{Line-haul cost} = 116 + 0.00036S + L(0.31735 + 0.0001482S.$$

Moreover, the remainder of Equation 31 is the railroad yard operations cost:

$$\text{Yard operations cost} = (36.54I - 0.06669L) + (12.04Y - 0.06017L).$$

An analagous result holds for Equation 32.

These costs include only movement in the railcar, not trucking to and from a rail line, which is not true in the case of tailer-on-flat-car (TOFC). Morlok (1978) reports the cost of one TOFC shipment for a movement between New York and Chicago as:

$$\begin{aligned} VC_{TOFC} &= 193 + 0.00118S + (0.206 + 0.0001367S)L + (30.79I - 0.04266L) + (10.14Y - 0.033610L) \\ FAC_{TOFC} &= 193 + 0.02528S + (0.206 + 0.0002622S)L + (30.79I - 0.04266L + (10.14Y - 0.033610L) \quad , \end{aligned} \quad (33)$$

where VC_{TOFC} = TOFC variable cost per shipment ($) and

FAC_{TOFC} = fully allocated cost per shipment ($) for TOFC.

All other terms are the same as defined above.

The Interstate Commerce Commission recently developed a new computerized regulatory costing methodology, known as the Uniform Rail Costing System (URCS). The system will be used primarily by the ICC as the basis for developing rail service costs for input into regulatory rate proceedings. The system also may be acquired by carriers and shippers for similar purposes, and as familiarity is gained with the system, it may be used by carriers in other cost-related activities. Yevich and Johnson (1980) comment that apart from other major functions, it can be used to calculate the variable cost per unit of output within each functional rail activity area by account or cost element, and to calculate the total variable cost of the movement by applying the unit costs to specific rail movement output statistics.

C.7 WATERWAY TRANSPORTATION OF COAL

C.7.1 Introduction and Some Statistics

Coal transportation by barge is possible on about 25,000 miles of inland waterway in 48 states. The principal waterways in use in the United States for all commodities are listed in Table C.14.

Approximately 1700 companies are engaged in barge operations, using 4,100 towboats and 22,000 dry cargo barges with a total capacity of 26 million net tons. Of the coal shipped by barge in 1973, more than 69% was moved over the Mississippi River and Gulf Intracoastal Waterway. The remaining 26% and 5% were moved over the Great Lakes and tidewaters, respectively. In 1974, some 83% of all domestic coal loading was in the Ohio, Monongahela, and Green rivers in the Appalachian region. Principal export ports were Hampton Roads, Virginia (77%), and Baltimore (12%).

Table C.14. Waterways Handling More than 10 Million Tons, 1976

	Tons	Ton-Miles (10^3)	Miles per ton
Atlantic Cost			
Cape Cod Canal, Mass.	13,016,499	231,187	18
Channel to Newport News, Va.	17,967,014	89,835	5
Delaware River			
Trenton, N.J. to the sea	133,696,091	10,431,935	78
Between Philadelphia, Pa., & Trenton, N.J.	15,626,657	305,644	20
Philadelhpia, Pa., to the sea	133,123,319	10,126,290	76
East River, N.Y.	45,806,570	528,337	12
Hudson River			
Deep water in Upper Bay, N.Y. to Waterford, N.Y.	28,308,347	1,923,483	68
Mouth of Spuyten Duyvil Creek (Harlem River) to Waterford, N.Y.	24,279,222	1,657,641	68
Hudson River Channel, N.Y. & M.J.	26,491,184	265,843	10
Inland waterway from Delaware River to Chesapeake Bay, Del. & Md.	11,257,613	517,533	46
Lower entrance channels, N.Y. Harbor	114,082,796	1,140,828	10
New York & New Jersey channels, N.Y. & N.J.	130,130,897	1,518,526	12
Newark Bay, N.J.	26,058,970	65,465	3
Schuylkill River, Pa.	13,781,512	41,981	3
Upper Bay, N.Y. Harbor, N.Y. & N.J.	159,285,234	512,431	3
Great Lakes			
Channels in Lake St. Clair, Mich.[a]	92,441,331		
Chicago Sanitary & Ship Canal, Ill.	23,629,761	360,139	15
Detroit River, Mich.	104,551,813	2,800,853	27
Illinois Waterway, Ill.	46,853,608	8,988,508	192
Rouge River, Mich.[b]	11,061,877		
St. Clair River, Mich.	96,360,190	3,530,997	37
St. Marys Fall Canal, Mich. & Sault St. Marie, Ontario Ship Canal, Canada[b]	76,739,521		
St. Marys River, Mich.	78,930,737	4,631,981	59
Gulf Coast			
Bayou Casotte, Miss.	20,478,068	91,952	4
Black Warrior & Tombigbee Rivers, Ala.	14,705,635	4,403,614	299
Calcasieu River & Pass, La.	20,221,283	457,493	23
Corpus Christi Ship Channels, Tex.	43,492,959	930,884	21
Gulf Intracoastal Waterway:			
Between Apalachee Bay, Fla. & the Mexican border	99,085,379	16,511,686	167
Morgan City-Port Allen route	18,961,414	1,160,489	61
Sabine-Neches Waterway, Tex.	100,852,284	3,000,149	30
Mississippi River System			
Monongahela River, Pa. & W.Va.	36,489,211	1,519,898	42
Ohio River, Pittsburgh to mouth of Tennessee	148,417,810	34,371,649	232
River, Tenn., Ala., & Ky.	26,254,165	3,663,745	140
Cumberland River:			
Mouth to Mile 552 (NET)	11,318,873	1,085,376	96
Mouth to Nashville, Tenn.	11,227,048	1,074,627	96
Green & Barren Rivers, Ky.	13,781,231	1,203,359	87
Illinois River, Ill.	43,065,859	8,475,497	197
Kanawha River, W.Va.	12,250,362	662,228	54
Mississippi River:			
Minneapolis, Minn. to mouth of passes	356,183,727	135,220,849	380
Minneapolis, Minn. to mouth of Missouri River	68,420,307	11,696,551	171
Mouth of Missouri River to mouth of Ohio River	78,138,431	13,217,186	169
Mouth of Ohio River to, but not including, Baton Rouge, La.	121,912,345	73,329,306	601
Baton Rouge, La. to, but not including, New Orleans, La.	243,831,754	16,757,970	69
New Orleans, La. to mouth of passes	232,614,050	20,219,837	87
Pacific Coast	24,224,013	162,245	7
Carquinez Strait, Calif.	24,244,013	162,245	7
Columbia River:			
Mouth to International Boundary	41,960,981	3,630,341	87
Columbia & Lower Willamette Rivers below Vancouver, Wash. & Portland, Oreg.	42,395,122	2,496,838	59
San Pablo & Mare Island Strait, Calif.	29,491,610	339,567	12

From U.S. Department of the Army (1977).

[a]Included in St. Clair River, Mich.

[b]Ton-miles--not reported.

C.7.2 Operations, Towboats and Barges

The towboats that operate on the inland waterways range in size from less than 1,000 hp to 10,500 hp. The distribution probably represents the optimal sizes given the present state-of-the-art in towboat design. Any further increase in horsepower is limited due to such physical restrictions as lock size and channel depth (9 feet).

The crew size of a towboat ranges from 7 to 14 for line-haul service. The crew work in six-hour shifts with six hours off between shifts. The boats generally operate year-round and 24 hours a day except for the time off needed for maintenance.

Most coal barges today are open-hopper designs with capacities ranging from 900 to 1800 metric tons, with an expected trend towards the lower half of this range.

The hopper barge is basically a double-skinned steel box, the inner shell forming a long open cargo hold, free of any obstructions and adapted for unloading with clamshell buckets, pallets, or continuous belt buckets. Table C.15 shows some typical sizes for open hopper barges.

Table C.15. Typical Barge Sizes

Length (ft)	Width (ft)	Draft (ft)	Capacity (metric ton)
175	26	9	900
195	35	9	1350
290	50	9	2700

The 175-ft barges may be used on almost all waterways but are required on those with small, typically old, locking facilities. The 195-ft barges may be used in tows operating through 600-ft or larger locks. Larger barges may operate, with a smaller number per tow, on rivers with 600-ft locks but are more efficiently placed on open channel rivers or those with 1200-ft locks.

The push-towing method is used in all line-haul operations on the inland waterway system. In push-towing operations, barges in the tow are lashed together by a complex system of cables to form a single unit. This unit is lashed solidly against the towboat's towing knees. The assembling, breaking, and reassembling of a tow consumes costly time and manpower. Constant readjustment of the towing cables is necessary during a voyage. Equipment failures are expensive and potentially dangerous. Given the number of lockages and double lockages required on some of the waterways with their attendant delays, it would seem that a moderate expenditure of research time and money spent on alternatives to lashing would produce major time and cost savings.

A towboat may push one barge or any multiple of barges ranging upwards of 45 barges when the tow is operating in open water.

On channels the number of barges in a tow is generally between 10 and 36, determined by lock sizes and also by the capacity of the river. As with unit train, most barges return empty when the distance is less than 800 km.

For passage through locks, barges are grouped four wide and three long or three wide and three or four long, depending on the size of the barges and the size of the locks to be transited. For maximum efficiency, tows are arranged as much as possible as dedicated tows. In this type of tow, the towboat remains with the barges during loading, unloading, and round trip transit. The towboat is generally owned by the shipper or contracted for exclusive use over a stipulated period of time. The advantages of this form of service are the ability to utilize an integrated towing operation, since all barges will be carrying one type of bulk commodity to a common destination; fast turn-around time resulting in reduced inventory cost; insurance; and reduced leasing cost or ownership cost of the barges per ton of shipment handled.

C.7.3 Waterway Network

The waterway modal network represents major U.S. inland waterway systems, including the Atlantic Intracoastal Waterway, the Gulf Intracoastal Waterway, the Pacific Intracoastal System, and the

Great Lakes. The St. Lawrence Seaway, which provides access to the Great Lakes, is part of the domestic deep-draft system and is also considered. For 1975, the network had the following dimensions:

	Elements	Classes
Nodes	434	23
Line-haul links	457	30
Access links	234	11
ICFs	116	--

The waterway network requires a relatively large number of classes and functions to allow for variation of river characteristics, lockage times, and other factors which affect commodity flow. Since lock characteristics vary, the node classes, for the most part, correspond to locks on different river systems. Each class uses functions that describe the locks on the river system.

C.7.4 Waterway Costs

The barge industry, unlike other transportation industries, is largely unregulated. All liquid bulk commodities and most dry bulk commodities transported by for-hire carriers and companies engaged in private transportation for their own commodities are exempted from ICC regulations. As a result, only 15% of the total ton-miles of barge traffic is under regulation (Rieber 1977).

A fuel tax of 4¢/gal for towing operations was introduced on October 1, 1980. This only applies to inland waterways; thus, it does not affect the transportation cost along the Atlantic coast. The 4¢/gal tax is scheduled to rise by 2¢/gal each year until it reaches 10¢/gal in 1985.

Some general guidelines on the financial status of waterway towing firms have been prepared (Burns and Mickle 1979). These data give approximations of the financial nature of the industry and are listed in Table C.16.

As indicated in Table C.16, expenses or operating costs, when compared with the revenue dollar, differ significantly between small firms and large firms. For small firms, profit before tax represents 8% of the revenue dollar; for larger firms, it represents 12.8%. For whatever reasons, the smaller firms display less efficiency in converting the revenue dollar into income.

Table C.16. Analysis of Tow Firms

Size of Firm	Turnover[a]	Margin[b] (%)
Small	1.0	8.0
Large	0.64	12.8
All	0.74	11.2

[a]Sales/total assets.

[b]Income/sales.

Due to the unregulated nature of the industry, it can be concluded that if the firm's operating cost can be estimated, then the cost to the shipper is simply that cost plus the profit margin.

The revenue profit given above was based on a sample of 13 firms that represent about 48% of Tennessee-based towing firms.

Barge transport costs can be estimated by first determining towboat and barge ownership and operating costs on an annualized basis from facility descriptions. Then these are converted to hourly ownership and operating costs specific to each waterway and for the relevant range of barge and towboat sizes. Terminal costs, tow make-up and break-up costs, and operating costs must be estimated and added. Among Tennessee firms surveyed, fuel averaged 31.2% of operating costs.

Other studies have shown that tow-related costs are dominated by fuel and depreciation, whereas most of the remaining costs in the crew category are dominated by wages and fringe benefits. In these studies, it was found that fuel costs currently represent about one-third of total operating costs.

The size and shape of a tow, the size of the towboat, the cargo capacity of a barge, and the capacity of a waterway are largely determined by the physical dimensions of the waterway as well as by the locks located on them. On most of the waterways in the system dams are constructed to provide adequate channel depth for barge navigation by creating a stepped series of lakes, at least 9 feet deep in most cases, in place of the flowing river. The size of the lock chamber controls the dimensions of the vessels using the waterways. For example, a 110-ft by 600-ft lock allows a group of nine 35-ft by 195-ft barges to pass through in one lockage operation and a tow of 15 barges and a towboat to pass through using a double lockage operation. Second, smaller lock chambers require the breakup of large tows. This breakup and reassembly of tows requires additional time which, together with two lockage operations, imposes an additional cost on barge transportation.

Actual capacities are considerably smaller than theoretical ones. First, navigation may not be possible year-round. Second, many tows are not optimally sized; lock capacity is wasted. Third, pleasure craft may not be denied a lockage for more than two lockings; every third lockage could be non-cargo. Fourth, all barges are not loaded. Perhaps as many as 40% are returning empty. Fifth, many barges are not in the 1500-ton class (Rieber 1977).

C.7.5 Lock Cost and Time Functions

Locks are represented as nodes in the waterway network. They are grouped into node classes according to river system, lock chamber size, and lock capacity and transit time characteristics.

Lock capacity and transit time have been estimated with U.S. Department of Transportation's Transportation Systems Center (TSC) LOKCAP model, which uses queueing theory to predict locking time and delay for individual locks. Inputs to LOKCAP, including tow size distributions and locking times, were derived from data collected by the Corps of Engineers Performance Monitoring System in 1975.

The results of the lock classification and capacity analysis are presented in Table C.17. The final three columns in the table provide parameter estimates for the lock time functions. The following hyperbolic function is used:

$$t = 2t_0 - T_1 + \frac{Q(T_1 - T_0)}{Q-q} ,$$

where t = lock transit time, including delay time,

q = annual lock traffic (net weight, 10^3 ton),

Q = theoretical lock capacity (10^3 ton),

T_0 = lock transit time at q=0, and

T_1 = lock transit time at q=0.5Q.

Parameters Q, T_0, and T_1 are provided directly in the LOKCAP output. This function is plotted for a number of different lock classes in Figure C.15.

Data on costs experienced by the towing industry in locking operations were taken from a run of the TSC Water Cost Model. Some of the unit cost input to that run, based on industry surveys conducted by the Corps of Engineers, are summarized in Table C.18.

The lock cost function is also of the hyperbolic type, namely

$$\text{Cost} = 2C_0 - C_1 + \frac{Q(C_1 - C_0)}{Q-q} \quad [\$/10^3 \text{ ton}] ,$$

where C_0 = lock cost at q=0 and

C_1 = lock cost at q=0.5Q.

Table C.19 and Figure C.16 display this function for a variety of lock classes and parameter values.

Table C.17. Lock Classes and Time Functions

		Locks Included						
		Dimensions (ft)				Time Functions		
		Chamber A		Chamber B				
Class	River	Length	Width	Length	Width	Q (10^3 ton)	T_0 (min)	T_1 (min)
UM600.110	Mississippi	600	110			50,000	65	100
UM.LD26	Mississippi	600	110	360	110	70,000	100	150
IL600.110	Illinois	600	110			50,000	75	125
	Ohio	600	110					
	Tennessee	600	110					
	Cumberland	800	110					
AK600.110	Arkansas	600	110			45,000	40	60
	Monongahela	600	84					
	GIWW[a]	797	75					
	Alabama/Coosa	655	84					
	Bl. Warrior/Tom-	600	110					
	bigbee/Mobile	520	95					
	Ouichita/Black	655	84					
OH12+6.110	Ohio	1200	110	600	110	120,000	50	70
	Mississippi	1200	110	600	110			
		1200	110	357	110			
OH.NAVPASS	Ohio	(LD52, LD53)				195,000	40	60
OH.GALLPLS	Ohio	600	110	360	110	60,000	70	110
OH600+360	Ohio	600	110	360	56	60,000	50	75
	Tennessee	600	110	360	60			
		600	110	400	60			
		600	110	292	60			
	Atchafalya/Old	1200	75					
MN360.56	Monongahela	360	56			40,000	60	90
	Allegheny	360	56					
	Ouichita/Black	300	55					
MN720.XX+	Monongahela	720	84	720	84	100,000	38	60
		720	56	360	56			
		720	110	360	56			
TNUM.360+	Tennessee	360	60			30,000	80	125
	Mississippi	400	56					
XX400+.75+	Clinch/Emory	400	75			35,000	30	50
	Cumberland	400	84					
	GIWW[a]	425	75					
	Ap/Ch/Fl[b]	505	82					
KW2X360.56	Kanawha	360	56	360	56	60,000	80	120
	Mississippi	400	56	400	56			
GIWW.XXXX	GIWW[a]	750	75			55,000	40	60
		1158	75					
		1204	75					
		1200	56					
		640	75					
		1198	84					
		800	75					
KY145.XX	Kentucky	145	38			4,500	55	90

[a]Gulf Intracoastal Waterway.

[b]Apalachicola/Chattahoochee/Flint.

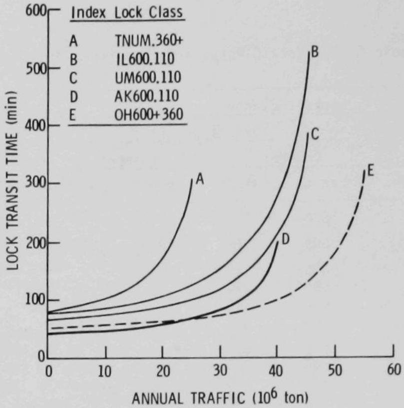

Fig. C.15. Lock Time Functions. Redrawn from Bronzini (1979a).

Table C.18. Towboat and Barge Operating Costs

Towboat Costs						
Towboat Horsepower	Max. Tow Size[a]	Labor Cost ($/hr)	Other Cost ($/hr)	Total Variable Cost ($/hr)[b] Operating	Total Variable Cost ($/hr)[b] Maneuvering	Annual Fixed Cost ($)
300	2	15.70	3.63	20.83	20.09	54,600
600	4	15.70	3.63	22.33	20.83	54,600
1,200	8	26.30	11.10	43.40	40.40	117,000
1,800	12	28.80	13.70	51.50	47.00	152,000
2,500	14	34.30	18.30	65.08	58.85	222,000
3,300	17	39,30	22.60	78.46	70.16	293,000
4,300	23	39.50	26.90	87.88	77.15	358,000
5,000	26	41.10	29.40	95.46	82.98	396,000
5,700	28	42.30	31.80	102.66	88.38	437,000
7,000	33	42.90	36.00	113.94	96.42	524,000
8,400	36	45.30	40.80	128.10	107.10	611,000
9,000	38	45.30	42.30	132.60	110.16	646,000
10,100	40	45.30	44.90	140.72	115.40	706,000

Barge Costs			
Barge Class	Capacity (ton)	Variable Cost ($/hr)	Annual Fixed Cost ($)
Open hopper jumbo	1700	0.55	19,300
Covered hopper jumbo	1700	0.66	22,900
Tank barge jumbo	1700	1.75	37,900

[a]Number of jumbo barges. Tow size may also be limited by channel characteristics.

[b]Sum of previous two columns plus fuel cost (based on 12¢/gal and fuel consumption of 1.0 gal/hp/day while operating and 0.5 gal/hp/day while maneuvering).

Table C.19. Lock Cost Function

Lock Class	No. of Locks	Average Locking Cost ($/kton-hr)		Cost Function[a]		
		Mean	Std. Dev.	0 (Ktons)	C_0 ($/kton)	C_1 ($/kton)
UM600.110	23	17.26	0.21	50,000	18.70	28.80
UM.LD26	1	16.92	--	70,000	28.20	42.30
IL600.110	24	16.92	1.35	50,000	21.20	35.20
AK600.110	32	16.39	7.30	45,000	10.90	16.40
OH12+6.110	10	15.59	1.35	120,000	13.00	18.20
OH.NAVPASS	2	18.58	1.46	195,000	12.40	18.60
OH.GALLPLS	1	15.49	--	60,000	18.10	28.40
OH.600+360	7	17.03	1.65	60,000	14.20	21.30
MN360.56	12	25.22	12.21	40,000	25.20	37.80
MN720.XX+	4	14.33	0.37	100,000	9.10	14.30
TNUM.360+	4	22.07	1.55	30,000	29.40	46.00
XX400+.75+	5	31.91	12.99	35,000	16.00	26.60
KW2X360.56	4	16.86	2.85	60,000	22.50	33.70
GIWW.XXXX	7	17.09	3.95	55,000	11.40	17.10
KY145.XX	6	46.29	0.04	4,500	42.40	69.40

Figure C.16

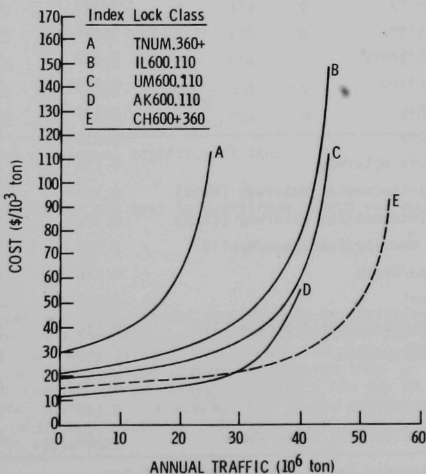

Fig. C.16. Lock Cost Functions. Redrawn from Bronzini (1979a).

C.7.6 Link Cost and Time Functions

Waterway channels are represented as line-haul links in the waterway network. They are grouped into link classes according to major river systems.

Channel travel speeds were obtained from a run of the INSA inland navigation simulation model, which is also available as part of the TSC Waterway Cost Model. Downstream and upstream travel speeds were plotted against annual channel traffic. The resulting travel time functions selected for each link class are given in Table C.20. In all cases, the function is either constant or exhibits a small positive slope. Slower speeds occur with increasing traffic because tow sizes tend to increase, with a consequent increase in tow resistance and a decrease in the horsepower-to-tonnage ratio.

Link function multipliers are used for certain classes to adjust for differences in upstream and downstream costs and time. The link cost is obtained by multiplying the travel time with actual cost per hour. The results of this calculation are displayed in Table C.21.

Table C.20. Waterway Line-Haul Link Classes and Time Functions

Link Class	Rivers Included	Downstream Travel Rate (hr/mi)[a] A	Downstream Travel Rate (hr/mi)[a] BX1000	Upstream Factor[b]
LWR.MISS.R	Lower Mississippi	0.04	0.678	1.5
UPR.MISS.R	Upper Mississippi	0.128	0	1.25
ARKANSAS.R	Arkansas	0.155	0	1.46
OHIO.RIVER	Ohio	0.10	0.457	1.0
L.MONONGHL	Lower Monongahela	0.132	0	1.0
U.MONONGHL	Upper Monongahela	0.132	0	1.0
ALLEGHENY	Allegheny	0.139	0	1.0
TENNESSEE	Tennessee	0.115	0.171	1.0
CLINCH/EMY	Clinch/Emory	0.128	0	1.0
CUMBERLAND	Cumberland	0.128	0	1.0
KANAWHA.R	Kanawha	0.146	0	1.0
KENTUCKY.R	Kentucky	0.139	0	1.0
ILLINOIS.R	Illinois Waterway	0.135	0	1.0
GIWW.WEST	Gulf Intracoastal Waterway (West)	0.155	0	1.0
GIWW.EAST	Gulf Intracoastal Waterway (East)	0.132	0	1.31
BW/TOMB/MO	Black Warrior/Tombigbee/Mobile	0.155	0	1.0
ALABA/COOS	Alabama/Coosa	0.146	0	1.0
MISSOURI.R	Missouri	0.110	0	2.05
AP/CHAT/FL	Apalachicola/Chattahoochee/Flint	0.114	0	1.65
ATCHAF/OLD	Atchafalaya/Old	0.106	0	2.13
RED.RIVER	Red	0.135	0	1.0
OUACHTA/BL	Ouachita/Black	0.146	0	1.0
P.ALLEN.RT.	Morgan City-Port Allen Route	0.135	0	1.0

[a]Travel rate = $A+Bq$ where q = annual link traffic, 10^6 ton.

[b]Ratio of upstream travel rate to downstream travel rate. In most cases, no differential was observable in the simulation model output. The small downstream current in slackwater pools is apparently counteracted by reduced draft due to a tendency toward movement of empty barges upstream.

Table C.21. Waterway Line-Haul Link Energy and Cost Functions

Link Class	Fuel Use (gal/tow-hr)	Avg. Tow Cargo Load[a] A	B	Downstream Energy Use (Btu/ton-mi)[b] C	D	Upstream Factor[c]	Downstream Cost (mills/ton-mi)
LWR.MISS.R	191	5960	58	178	0.678	1.5	2.75
UPR.MISS.R	111	5960	58	277	0	1.25	3.40
ARKANSAS.R	45	4950	0	195	0	1.46	3.90
OHIO.RIVER	75	5440	25	191	0	1.0	2.75
L.MONONGHL	26	2190	35	187	0	1.0	3.15
U.MONONGHL	26	2190	35	187	0	1.0	3.15
ALLEGHENY	23	2240	0	198	0	1.0	2.75
TENNESSEE	78	6450	0	193	0.286	1.0	3.15
CLINCH/EMY	41	3260	0	223	0	1.0	3.00
CUMBERLAND	41	3260	0	223	0	1.0	3.00
KANAWA.R	33	3600	0	187	0	1.0	3.00
KENTUCKY.R	25	670	0	719	0	1.0	5.50
ILLINOIS.R	82	6190	0	248	0	1.0	3.15
GIWW.WEST	25	3070	0	175	0	1.0	3.60
GIWW.EAST	27	3070	0	164	0	1.31	3.80
BW/TOMB/MO	25	3280	0	164	0	1.0	3.15
ALABA/COOS	25	960	0	527	0	1.0	5.00
MISSOURI.R	73	3530	0	315	0	2.05	5.50
AP/CHAT/FL	25	970	0	379	0	1.65	9.40
ATCHAF/OLD	25	2100	0	175	0	2.13	7.50
RED.RIVER	25	910	0	514	0	1.0	6.30
OUACHTA/BL	25	910	0	556	0	1.0	5.50
P.ALLEN.RT	25	1600	0	293	0	1.0	3.60

[a]Tons/tow = A+Bq where q = annual traffic, 10^6 ton.

[b]Btu/ton-mile = C+Dq.

[c]Ratio of upstream energy use and cost to downstream energy use and cost.

C.7.7 Ports

Waterway ports were grouped into node classes according to the relative amount of fleeting activity occurring, as revealed in a simulation of the inland waterway system conducted for the Corps of Engineers. Fleeting costs were derived from analysis of output from the TSC Waterway Cost Model, which indicated that fleeting type activities at ports incur an average cost of $0.25 per ton. It was assumed that cargo would be delayed awaiting a tow for 24 hours, and that a fleeting stop would delay a tow for 3 hours. The average tow in the model consists of 7 barges and a 2000-horsepower towboat, with a net load of 5600 tons. Port time and cost estimates based on this analysis are given in Table C.22.

According to a study based on Corps of Engineers' data, the average terminal time for loading coal is 72 hours; for unloading, it is 120 hours. The basis for these estimates is not given, however (Rieber 1977).

C.7.8 Waterway Coal Terminals--Rail to Barge

Major requirements include a car dumper, a system for conveying coal to either storage piles or directly to the barges for loading, equipment for storing coal and subsequently reclaiming it for barge loadout, and a barge loading system. The barge loading system is simply a conveyor on a structural boom with head level adjustable to the level of the river.

Table C.22. Port Time, Cost and Energy Functions

Node Class	Avg. of Tows Stopping	Time (hr)	Energy Use (Btu/ton)	Cost ($\$/10^3$ ton)
--	100	27	3000	250
MAJR. FLEET	90	24	2700	225
IMMD. FLEET	60	16	1800	150
MINR. FLEET	30	8	900	75
THRU+ACCESS	0	0	0	0

A terminal designed for an annual throughput of 10^6 ton/yr would require coal storage capacity for about 500,000 tons. It would handle approximately three 100-car unit trains per day over a 350-day working year. Normal processing time is 40 cars per hour (30 if the coal requires thawing). Barge loading can be accomplished at the rate of 6,000 ton/hr. However, if the barges are loaded directly from the unit train, the loading rate is 4,000 ton/hr. On a daily basis, the throughput of 30,000 tons amounts to loading 1.3 tows, of 15 barges each, per day (Rieber 1977).

The hours required to break up an incoming tow for loading (T_b) and to make up a tow after loading (T_m) may be, respectively, expressed as (2):

$$T_b = 0.34 + 0.2 \times (\text{number of barges})$$

$$T_m = 0.21 + 0.44 \times (\text{number of barges}).$$

The approximate capital cost for a 10-million-ton-per-year facility, including equipment, material, contract services, and labor is $16.5 million (1976). Operation requires approximately 40 people, including supervisors, equipment operators, mechanics, clerks, electricians, and general labor. While no estimates were available, operating costs are a function of throughput. However, the relationship is not linear. There are economies of scale. The limits to these economies depend on the time required to dump a train, maximum conveyor belt carrying capacity, barge arrival time irregularities, and dock space for barges (five barges in the description above). The facility described above may be optimal for a large facility with a single loading boom.

Based on the above admittedly sketchy data, it is possible to make a gross estimate of per-ton terminal costs. Adding contingencies and working capital to the $16.05 million, a total capital cost of $19.41 million is estimated. Given a 25-year life, annual fixed charges, including depreciation, taxes and insurance, may be estimated at $2.193 million. Operation and maintenance costs are estimated at $1.866 million. This includes $600,000 for labor, $281,000 for fuel, $607,000 for maintenance and supplies, and $378,000 for overhead. The above is consistent with the costing parameters used for rail and slurry pipelines. Total annual costs are therefore $4,059,000 or 40.6¢/ton at the receiving end. Assuming that the delivery end, assumed to be an electric utility, requires only one-fifth the throughput capacity, total terminal costs are estimated at 48.7¢/ton (Rieber 1977).

C.7.9 Transportation Cost as a Function of Distance

An overall profile emerges in which the most important factor in modal choice is the distance between origin and destination: the longer the distance is, the more likely is the movement by water. The cost and time of barge loading and unloading require a reasonably long haul to make the water mode attractive. Increasing value per ton has a depressing effect over long hauls because of the slower speed of the water mode and its effect on inventory costs.

The following equation was given by Szabo (1978), and expresses the relationship of cost to distance for barge transportation of coal:

$$C = 20.93\ D^{-0.285}\ ,$$

where C = barge transportation rate (based on 1970 dollars), mills/metric ton-km (mills/ton-mi) and

D = one-way barge distance, km (mi).

In addition, a charge of 36¢ per metric ton (40¢ per ton) was included for all barge/rail or rail/barge transfer.

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APPENDIX D. RAIL FORM A CALCULATIONS

In this appendix, the derivation of operating ($) cost functions for rail line haul is presented by way of an example. The example considered here is handling coal in general open hopper type of car. The Official Rail Territory (eastern) Rail Form A-1977 is used in these calculations. Single line operations and no interline exchanges are assumed (see Tables D.1 and D.2).

Divide the equation in line 16 of Table D.1 by T to obtain

$$\text{Cost/ton in cents} = 51.0539093 \frac{l_a}{T} + 0.92874\ l_a + 3.191\ . \qquad (1)$$

It is assumed that 83.5 tons of coal can be loaded on a general hopper car. Substituting T = 83.5 tons in Equation 1 the cost of transporting coal in cents/ton can be expressed as:

$$C_c = 3.191 + 1.5401641\ l_a\ . \qquad (2)$$

To calculate the line haul operating cost function for non-coal commodities, the same method as for coal is used. Other types of railroad cars to transport non-coal commodities and their cost functions are considered. A general open-type hopper car is not condsidered here as it is assumed to transport coal only. The other types of cars considered and the fleet statistics that are given in Armstrong (1979) are presented in Table D.3. The cost functions in cents/ton for the cars are given in Table D.4. The cost functions for various car types were aggregated by the number of cars of that type to obtain a cost function for non-coal commodities:

$$C_{nc} = \frac{\sum_i C_i n_i}{\sum_i n_i}\ , \qquad (3)$$

where C_{nc} = cost of transportation of non-coal commodities,

C_i = cost of transportation of non-coal commodity by railroad car type i, and

n_i = number of railroad cars of type i, given in Table D.3.

The aggregate cost function for transporting non-coal commodities using Equation 3 is:

$$C_{nc} = 18.561 + 2.363624\ l_a\ . \qquad (4)$$

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Table D.1. Line Haul Operating Cost for Handling Coal in General Open Hopper

	Total Variable Cost	Reference in Rail Form A, Output	Cost
1.	Cost/car-mile (average train, including empty)	Sum.1, Sh.1.2, L.18, c.8 (B3612)[a]	51.0539093 ¢
2.	Cost/gross-ton-mile	Sch.B, Sh.1.9, L.19, c.5 (B3417)[b]	0.50080 ¢
3.	Tons of loading (contents of car)		T tons
4.	Loading cost/car-mile	L.2 X L.3	0.50080T ¢
5.	Total cost/car-mile	L.4 X L.1	51.0539093 + 0.5008T ¢
6.	One way actual miles		1_a
7.	Cost/car	L.6 X L.5	$(51.0539093 + 0.5008T)\ 1_a$
Freight Claims			
8.	Carload claims clerical, cost/ton	Sum.1, Sh.1.2, L.244, c.8 (B3738)[c]	1.009 ¢
9.	Loss and damage claim payment, cost/ton	Statement ICI-77, STC11[d]	2.182 ¢
10.	Total cost/ton		3.191 ¢
11.	Cost/car	L.3 X L.10	33.191T ¢
12.	Total variable cost	Σ lines 7, 11	$[(51.0539003 + 0.5008T)1_a + 3.191T]$
Total Constant Cost			
13.	Cost/ton-mile	See Table D.2	0.42794 ¢
14.	Cost/ton	L.13 X L.6	$0.42794.\ 1_a$
15.	Cost/car		$0.42794\ 1_a \cdot T$ ¢
16.	Total line haul cost	Σ Line 12, 15	$[(51.0539093 + 0.92874T)\ 1_a + 3.191T]$

[a]Sum.1, Sh.1.2, L.18, c.8 is a reference in Rail Form-A. Procedure: look up Summary 1, Sheet 1.2, Line 18 and column 8, for hopper open general type of car, which gives the reference number B3612. Then refer to the variable B numbers output and the number B3612, to find 51.0539093 ¢.

[b]Sch.B, Sh.1.9, L.19, c.5 is a reference in Rail Form-A. Procedure: refer to Schedule B, Sheet 1.9, Line 9 and Column 5 to obtain B3417, which is 0.50080 ¢.

[c]Sum.1, Sh.1.2, L.24, c.8 is a reference in Rail Form-A. Procedure: refer to Summary 1, Sheet 1.2, Line 24 and column 8 to get B3728, which is 1.009 ¢.

[d]Statement ICI-77. is the Rail Carload Cost Scales Report published in 1977. STCC II refers to the commodity code for coal which is II. In Appendix A of Statement ICI-77, find for coal, carload freight claims paid by railroad due to loss and damages to commodity in shipment.

Table D.2. Calculation of Constant Cost for Line Haul Operating Cost for Coal

Constant Cost Parameter	Reference in Rail Form-A, Output	Cost
1. Constant cost/ton-mile (interline)	Sch.D, Sh.1.9, L.2S, c.59 (B3413)[a]	0.46177 ¢
2. Interchange car-cost	Sch.D, Sh.1.7, L.5, c.48 (B3156)[b]	$7,357,993
3. Interchange engine-minute	Sch.D, Sh.1.8, L.5. c.56 (B3163)[c]	$64,100,576
4. Total interchange cost	L.2 + L.3	$71,458,569
5. Carload net ton-mile	Sch.D, Sh.1.10, Footnote 2 (B3365)[d]	211,254,837,248 ton-miles
6. Constant interchange cost per carload net ton-miles	L.4 + L.5	0.03383 ¢
7. Total constant cost/ton-mile (single line)	L.1 - L.6	0.42794 ¢

[a] Sch.D, Sh. 1.9, L.25, c.59 is a reference in Rail Form-A. Procedure: refer to Schedule D, Sheet 1.9, Line 25 and column 59 to obtain B3413, which is 0.46177 ¢.

[b] Sch.D, Sh. 1.7, L.5, c.48 is a reference in Rail Form-A. Procedure: refer to Schedule D, Sheet 1.7, Line 5 and column 48 to obtain B3156, which is $7,357,993.

[c] Sch.D, Sh. 1.8, L.5, c.56 is a reference in Rail Form-A. Procedure: refer to Schedule D, Sheet 1.8, Line 5 and column 56 to obtain B3163, which is $71,458,569.

[d] Sch.D, Sh. 1.10, Footnote 2 is a reference in Rail Form-A. Procedure: refer to Footnote 2 in Schedule D, Sheet 1.10 to obtain B3365, which is 211,254,837,248 ton-miles.

Table D.3. U.S. Railroad Fleet Statistics by Car Type as of 1979

Type of Car	No. of Cars	Average Capacity (ton)
Box car, general, equipped	174,000	31.8
Box car, general, unequipped	321,500	31.8
Gondola, general	1,016,000	67.2
Livestock car	4,400	54.2
Flat, general	141,000	54.3
Refrigerator	101,000	35.0
Tank, 28K	171,000	62.5

The average capacity of the car, by car type, has been taken from Interstate Commerce Commission (1977).

Table D.4. Line Haul Operating Cost Functions for Various Types of Cars

Type of Car	Cost Function
Box car, general, equipped	$18.561 + 2.3251845\ \ell_a$
Box car, general, unequipped	$18.561 + 2.8066253\ \ell_a$
Gondola, general	$18.561 + 1.6929369\ \ell_a$
Livestock car	$18.561 + 1.9025128\ \ell_a$
Flat, general	$18.561 + 1.896161\ \ell_a$
Refrigerator	$18.561 + 3.1778485\ \ell_a$
Tank, 28K	$18.561 + 2.2141297\ \ell_a$

ℓ_a = length of haul in miles.

APPENDIX E. REPORT WRITER 1

NORTHEAST REGIONAL COAL FLOWS FOR FUA CONVERSION CANDIDATES

Table E.1. Northeast Regional Annual Coal Flows for FUA Conversion Candidates, 1991 Oil SIP

FUA Plant	State	Coal Source	Annual Demand by Coal Type (% Sulfur) (Kilotons) 0.00-0.64%	0.65-1.04%	1.05-1.84%	1.85-2.24%	2.25-3.04%	3.05 +%	Trans-port Cost ($/ton)	Delay Cost ($/ton)	Carriers
Bridgeport Harbor	CT	State College, PA	0.0	0.0	0.0	0.0	145.0	0.0	8.93	1.36	Conrail Perth Amboy, NJ Intercoastal Barge
Bridgeport Harbor	CT	New Castle, PA	0.0	0.0	0.0	0.0	0.0	728.0	11.53	1.63	Conrail Perth Amboy, NJ Intercoastal Barge
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	145.0	728.0	11.09	1.59	
Devon	CT	State College, PA	0.0	0.0	0.0	0.0	72.0	0.0	8.97	1.38	Conrail Perth Amboy, NJ Intercoastal Barge
Devon	CT	New Castle, PA	0.0	0.0	0.0	0.0	0.0	359.0	11.56	1.65	Conrail Perth Amboy, NJ Intercoastal Barge
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	72.0	359.0	11.13	1.61	
Norwalk Harbor	CT	State College, PA	0.0	0.0	0.0	0.0	109.0	0.0	8.82	1.30	Conrail Perth Amboy, NJ Intercoastal Barge
Norwalk Harbor	CT	New Castle, PA	0.0	0.0	0.0	0.0	0.0	546.0	11.42	1.57	Conrail Perth Amboy, NJ Intercoastal Barge
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	109.0	546.0	10.99	1.52	
Montville	CT	State College, PA	0.0	0.0	0.0	0.0	38.0	0.0	9.36	1.62	Conrail Perth Amboy, NJ Intercoastal Barge
Montville	CT	New Castle, PA	0.0	0.0	0.0	0.0	0.0	189.0	11.96	1.89	Conrail Perth Amboy, NJ Intercoastal Barge
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	38.0	189.0	11.52	1.85	
Middletown	CT	State College, PA	0.0	0.0	0.0	0.0	136.0	0.0	9.37	1.63	Conrail Perth Amboy, NJ Intercoastal Barge

Table E.1. (continued)

FUA Plant	State	Coal Source	0.00-0.64%	0.65-1.04%	1.05-1.84%	1.85-2.24%	2.25-3.04%	3.05 +%	Transport Cost ($/ton)	Delay Cost ($/ton)	Carriers
			Annual Demand by Coal Type (% Sulfur) (Kilotons)								
Middletown	CT	New Castle, PA	0.0	0.0	0.0	0.0	0.0	681.0	11.97	1.90	Conrail Perth Amboy, NJ Intercoastal Barge
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	136.0	681.0	11.54	1.85	
Edge Moor	DE	State College, PA	0.0	0.0	0.0	0.0	838.0	0.0	6.86	0.51	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	838.0	0.0	6.86	0.51	
Mason	ME	New Castle, PA	0.0	0.0	0.0	436.0	0.0	0.0	13.61	2.47	Conrail Perth Amboy, NJ Collier
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	436.0	0.0	0.0	13.61	2.47	
Brandon Shores	MD	Uniontown, PA	0.0	0.0	0.0	0.0	2288.2	0.0	8.31	0.51	CSX Corp. Curtis Bay, MD Intercoastal Barge
Brandon Shores	MD	Johnstown, PA	0.0	0.0	0.0	0.0	746.8	0.0	7.35	0.45	CSX Corp. Curtis Bay, MD Intercoastal Barge
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	3035.0	0.0	8.07	0.49	
Riverside	MD	State College, PA	0.0	0.0	0.0	0.0	137.0	0.0	6.46	0.49	Conrail Power Plant RR Link
Riverside	MD	Uniontown, PA	0.0	0.0	0.0	0.0	196.5	0.0	7.19	0.34	CSX Corp. Power Plant RR Link
Riverside	MD	Johnstown, PA	0.0	0.0	0.0	0.0	27.5	0.0	6.23	0.28	CSX Corp. Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	361.0	0.0	6.84	0.39	
Crane, C.P.	MD	State College, PA	0.0	0.0	0.0	0.0	859.0	0.0	6.46	0.49	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	859.0	0.0	6.46	0.49	
Wagner, H.A.	MD	State College, PA	0.0	0.0	0.0	0.0	618.0	0.0	6.46	0.49	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	618.0	0.0	6.46	0.49	

Table E.1. (continued)

FUA Plant	State	Coal Source	Annual Demand by Coal Type (% Sulfur) (Kilotons) 0.00-0.64%	0.65-1.04%	1.05-1.84%	1.85-2.24%	2.25-3.04%	3.05 +%	Transport Cost ($/ton)	Delay Cost ($/ton)	Carriers
Middletown	CT	New Castle, PA	0.0	0.0	0.0	0.0	0.0	681.0	11.97	1.90	Conrail Perth Amboy, NJ Intercoastal Barge
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	136.0	681.0	11.54	1.85	
Edge Moor	DE	State College, PA	0.0	0.0	0.0	0.0	838.0	0.0	6.86	0.51	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	838.0	0.0	6.86	0.51	
Mason	ME	New Castle, PA	0.0	0.0	0.0	436.0	0.0	0.0	13.61	2.47	Conrail Perth Amboy, NJ Collier
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	436.0	0.0	0.0	13.61	2.47	
Brandon Shores	MD	Uniontown, PA	0.0	0.0	0.0	0.0	2288.2	0.0	8.31	0.51	CSX Corp. Curtis Bay, MD Intercoastal Barge
Brandon Shores	MD	Johnstown, PA	0.0	0.0	0.0	0.0	746.8	0.0	7.35	0.45	CSX Corp. Curtis Bay, MD Intercoastal Barge
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	3035.0	0.0	8.07	0.49	
Riverside	MD	State College, PA	0.0	0.0	0.0	0.0	137.0	0.0	6.46	0.49	Conrail Power Plant RR Link
Riverside	MD	Uniontown, PA	0.0	0.0	0.0	0.0	196.5	0.0	7.19	0.34	CSX Corp. Power Plant RR Link
Riverside	MD	Johnstown, PA	0.0	0.0	0.0	0.0	27.5	0.0	6.23	0.28	CSX Corp. Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	361.0	0.0	6.84	0.39	
Crane, C.P.	MD	State College, PA	0.0	0.0	0.0	0.0	859.0	0.0	6.46	0.49	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	859.0	0.0	6.46	0.49	
Wagner, H.A.	MD	State College, PA	0.0	0.0	0.0	0.0	618.0	0.0	6.46	0.49	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	618.0	0.0	6.46	0.49	

Table E.1. (continued)

FUA Plant	State	Coal Source	Annual Demand by Coal Type (% Sulfur) (Kilotons) 0.00-0.64%	0.65-1.04%	1.05-1.84%	1.85-2.24%	2.25-3.04%	3.05 +%	Transport Cost ($/ton)	Delay Cost ($/ton)	Carriers
New Boston	MA	State College, PA	0.0	1620.0	0.0	0.0	0.0	0.0	10.36	1.95	Conrail Perth Amboy, NJ Collier
Plant Totals & Mean Transport & Delay Cost:			0.0	1620.0	0.0	0.0	0.0	0.0	10.36	1.95	
Mystic	MA	State College, PA	0.0	957.0	0.0	0.0	0.0	0.0	10.36	1.95	Conrail Perth Amboy, NJ Collier
Plant Totals & Mean Transport & Delay Cost:			0.0	957.0	0.0	0.0	0.0	0.0	10.36	1.95	
Canal	MA	State College, PA	0.0	1059.0	0.0	0.0	0.0	0.0	10.09	1.85	Conrail Perth Amboy, NJ Collier
Plant Totals & Mean Transport & Delay Cost:			0.0	1059.0	0.0	0.0	0.0	0.0	10.09	1.85	
Mount Tom	MA	State College, PA	0.0	285.0	0.0	0.0	0.0	0.0	11.37	0.85	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	285.0	0.0	0.0	0.0	0.0	11.37	0.85	
Salem Harbor	MA	State College, PA	0.0	689.0	0.0	0.0	0.0	0.0	10.37	1.95	Conrail Perth Amboy, NJ Collier
Plant Totals & Mean Transport & Delay Cost:			0.0	689.0	0.0	0.0	0.0	0.0	10.37	1.95	
Somerset	MA	State College, PA	0.0	248.0	0.0	0.0	0.0	0.0	9.80	1.74	Conrail Perth Amboy, NJ Collier
Plant Totals & Mean Transport & Delay Cost:			0.0	248.0	0.0	0.0	0.0	0.0	9.80	1.74	
West Springfield	MA	State College, PA	0.0	227.0	0.0	0.0	0.0	0.0	11.41	0.85	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	227.0	0.0	0.0	0.0	0.0	11.41	0.85	
Schiller	NH	New Castle, PA	0.0	0.0	0.0	406.0	0.0	0.0	13.18	2.31	Conrail Perth Amboy, NJ Collier
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	406.0	0.0	0.0	13.18	2.31	

Table E.1. (continued)

FUA Plant	State	Coal Source	Annual Demand by Coal Type (% Sulfur) (Kilotons) 0.00-0.64%	0.65-1.04%	1.05-1.84%	1.85-2.24%	2.25-3.04%	3.05 +%	Transport Cost ($/ton)	Delay Cost ($/ton)	Carriers
Deepwater	NJ	Johnstown, PA	0.0	0.0	0.0	0.0	0.0	174.8	7.87	0.76	CSX Corp. Curtis Bay, MD Intercoastal Barge
Deepwater	NJ	Hagerstown, MD	0.0	0.0	0.0	0.0	0.0	288.2	5.03	0.55	CSX Corp. Curtis Bay, MD Intercoastal Barge
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	0.0	463.0	6.10	0.63	
Sayreville	NJ	State College, PA	0.0	0.0	0.0	0.0	344.0	0.0	7.19	0.89	Conrail Power Plant RR Link
Sayreville	NJ	New Castle, PA	0.0	0.0	0.0	0.0	0.0	178.0	9.79	1.17	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	344.0	178.0	8.07	0.99	
Bergen	NJ	State College, PA	0.0	0.0	0.0	0.0	752.0	0.0	7.54	0.55	Conrail Power Plant RR Link
Bergen	NJ	New Castle, PA	0.0	0.0	0.0	0.0	0.0	387.0	10.14	0.82	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	752.0	387.0	8.42	0.64	
Kearny	NJ	State College, PA	0.0	0.0	0.0	0.0	346.0	0.0	7.54	0.55	Conrail Power Plant RR Link
Kearny	NJ	New Castle, PA	0.0	0.0	0.0	0.0	0.0	178.0	10.14	0.82	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	346.0	178.0	8.42	0.64	
Sewaren	NJ	State College, PA	0.0	0.0	0.0	0.0	730.0	3.3	7.17	0.89	Conrail Power Plant RR Link
Sewaren	NJ	New Castle, PA	0.0	0.0	0.0	0.0	0.0	373.7	9.77	1.16	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	730.0	377.0	8.05	0.98	
Hudson	NJ	State College, PA	0.0	0.0	0.0	0.0	528.0	93.3	7.54	0.55	Conrail Power Plant RR Link

Table E.1. (continued)

FUA Plant	State	Coal Source	Annual Demand by Coal Type (% Sulfur) (Kilotons) 0.00-0.64%	0.65-1.04%	1.05-1.84%	1.85-2.24%	2.25-3.04%	3.05+%	Transport Cost ($/ton)	Delay Cost ($/ton)	Carriers
Hudson	NJ	New Castle, PA	0.0	0.0	0.0	0.0	0.0	179.7	10.14	0.82	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	528.0	273.0	8.12	0.61	
Burlington	NJ	State College, PA	0.0	0.0	0.0	0.0	0.0	191.6	6.73	0.80	Conrail Power Plant RR Link
Burlington	NJ	New Castle, PA	0.0	0.0	0.0	0.0	0.0	159.4	9.33	1.08	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	0.0	351.0	7.91	0.93	
Danskammer	NY	New Castle, PA	0.0	0.0	0.0	0.0	0.0	1134.0	11.57	1.66	Conrail Perth Amboy, NJ Intercoastal Barge
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	0.0	1134.0	11.57	1.66	
Arthur Kill	NY	New Castle, PA	0.0	0.0	0.0	1916.0	0.0	0.0	11.01	1.32	Conrail Perth Amboy, NJ Intercoastal Barge
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	1916.0	0.0	0.0	11.01	1.32	
Ravenswood	NY	New Castle, PA	0.0	0.0	0.0	1680.0	0.0	0.0	11.17	1.42	Conrail Perth Amboy, NJ Intercoastal Barge
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	1680.0	0.0	0.0	11.17	1.42	
Barrett, E.F.	NY	State College, PA	0.0	0.0	0.0	0.0	818.0	0.0	8.67	1.21	Conrail Perth Amboy, NJ Intercoastal Barge
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	818.0	0.0	8.67	1.21	
Northport	NY	State College, PA	0.0	0.0	0.0	0.0	0.0	174.8	8.78	1.27	Conrail Perth Amboy, NJ Intercoastal Barge
Northport	NY	New Castle, PA	0.0	0.0	0.0	2663.0	0.0	766.2	11.38	1.54	Conrail Perth Amboy, NJ Intercoastal Barge
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	2663.0	0.0	941.0	11.26	1.53	

Table E.1. (continued)

FUA Plant	State	Coal Source	Annual Demand by Coal Type (% Sulfur) (Kilotons) 0.00-0.64%	0.65-1.04%	1.05-1.84%	1.85-2.24%	2.25-3.04%	3.05 +%	Transport Cost ($/ton)	Delay Cost ($/ton)	Carriers
Far Rockaway	NY	New Castle, PA	0.0	0.0	0.0	275.0	0.0	0.0	11.21	1.44	Conrail Perth Amboy, NJ Intercoastal Barge
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	275.0	0.0	0.0	11.21	1.44	
Glenwood	NY	State College, PA	0.0	0.0	0.0	0.0	673.0	0.0	8.69	1.22	Conrail Perth Amboy, NJ Intercoastal Barge
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	673.0	0.0	8.69	1.22	
Port Jefferson	NY	New Castle, PA	0.0	0.0	0.0	1049.0	0.0	0.0	11.53	1.63	Conrail Perth Amboy, NJ Intercoastal Barge
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	1049.0	0.0	0.0	11.53	1.63	
Albany	NY	New Castle, PA	0.0	0.0	0.0	878.0	0.0	0.0	11.08	0.59	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	878.0	0.0	0.0	11.08	0.59	
Lovett	NY	State College, PA	0.0	0.0	0.0	0.0	1214.0	0.0	8.34	0.65	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	1214.0	0.0	8.34	0.65	
Oswego	NY	New Castle, PA	0.0	0.0	0.0	992.0	0.0	0.0	8.06	0.40	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	992.0	0.0	0.0	8.06	0.40	
Cromby	PA	New Castle, PA	0.0	0.0	0.0	0.0	0.0	424.0	8.83	1.00	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	0.0	424.0	8.83	1.00	
Schuylkill	PA	New Castle, PA	0.0	0.0	0.0	0.0	0.0	374.0	9.87	1.12	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	0.0	374.0	9.87	1.12	
Southwark	PA	New Castle, PA	0.0	0.0	0.0	0.0	0.0	1159.0	9.87	1.12	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	0.0	1159.0	9.87	1.12	

Table E.1. (continued)

FUA Plant	State	Coal Source	Annual Demand by Coal Type (% Sulfur) (Kilotons) 0.00-0.64%	0.65-1.04%	1.05-1.84%	1.85-2.24%	2.25-3.04%	3.05 +%	Transport Cost ($/ton)	Delay Cost ($/ton)	Carriers
Springdale	PA	Pittsburgh, PA	0.0	0.0	0.0	0.0	0.0	518.0	2.62	0.0	Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	0.0	518.0	2.62	0.0	
South Street	RI	State College, PA	0.0	0.0	0.0	0.0	200.0	0.0	9.81	1.74	Conrail Perth Amboy, NJ Collier
South Street	RI	New Castle, PA	0.0	0.0	0.0	0.0	0.0	91.0	12.41	2.01	Conrail Perth Amboy, NJ Collier
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	200.0	91.0	10.62	1.83	

Table E.2. Northeast Regional Annual Coal Flows for FUA Conversion Candidates, 1991 NSPS

FUA Plant	State	Coal Source	Annual Demand by Coal Type (% Sulfur) (Kilotons) 0.00-0.64%	0.65-1.04%	1.05-1.84%	1.85-2.24%	2.25-3.04%	3.05 +%	Transport Cost ($/ton)	Delay Cost ($/ton)	Carriers
Bridgeport Harbor	CT	New Castle, PA	0.0	0.0	0.0	0.0	0.0	873.0	11.52	1.29	Conrail Perth Amboy, NJ Intercoastal Barge
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	0.0	873.0	11.52	1.29	
Devon	CT	New Castle, PA	0.0	0.0	0.0	0.0	0.0	431.0	11.56	1.31	Conrail Perth Amboy, NJ Intercoastal Barge
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	0.0	431.0	11.56	1.31	
Norwalk Harbor	CT	New Castle, PA	0.0	0.0	0.0	0.0	0.0	655.0	11.42	1.22	Conrail Perth Amboy, NJ Intercoastal Barge
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	0.0	655.0	11.42	1.22	
Montville	CT	New Castle, PA	0.0	0.0	0.0	0.0	0.0	227.0	11.96	1.55	Conrail Perth Amboy, NJ Intercoastal Barge
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	0.0	227.0	11.96	1.55	
Middletown	CT	New Castle, PA	0.0	0.0	0.0	0.0	0.0	817.0	11.97	1.55	Conrail Perth Amboy, NJ Intercoastal Barge
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	0.0	817.0	11.97	1.55	
Edge Moor	DE	Uniontown, PA	0.0	0.0	0.0	0.0	838.0	0.0	8.73	0.53	CSX Corp. Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	838.0	0.0	8.73	0.53	
Mason	ME	Pittsburgh, PA	0.0	0.0	0.0	436.0	0.0	0.0	14.85	2.22	Conrail Perth Amboy, NJ Collier
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	436.0	0.0	0.0	14.85	2.22	
Brandon Shores	MD	Uniontown, PA	0.0	1320.2	0.0	0.0	0.0	0.0	8.31	0.53	CSX Corp. Curtis Bay, MD Intercoastal Barge

Table E.2. (continued)

FUA Plant	State	Coal Source	Annual Demand by Coal Type (% Sulfur) (Kilotons) 0.00-0.64%	0.65-1.04%	1.05-1.84%	1.85-2.24%	2.25-3.04%	3.05 +%	Transport Cost ($/ton)	Delay Cost ($/ton)	Carriers
Brandon Shores	MD	Johnstown, PA	0.0	753.8	0.0	0.0	0.0	0.0	7.35	0.46	CSX Corp. Curtis Bay, MD Intercoastal Barge
Brandon Shores	MD	Hagerstown, MD	0.0	960.9	0.0	0.0	0.0	0.0	4.51	0.24	CSX Corp. Curtis Bay, MD Intercoastal Barge
Plant Totals & Mean Transport & Delay Cost:			0.0	3035.0	0.0	0.0	0.0	0.0	6.87	0.42	
Riverside	MD	Uniontown, PA	0.0	361.0	0.0	0.0	0.0	0.0	7.19	0.36	CSX Corp. Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	361.0	0.0	0.0	0.0	0.0	7.19	0.36	
Crane, C.P.	MD	Uniontown, PA	0.0	859.0	0.0	0.0	0.0	0.0	7.19	0.36	CSX Corp. Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	859.0	0.0	0.0	0.0	0.0	7.19	0.36	
Wagner, H.A.	MD	Uniontown, PA	0.0	598.9	0.0	0.0	0.0	0.0	7.19	0.36	CSX Corp. Power Plant RR Link
Wagner, H.A.	MD	Hagerstown, MD	0.0	19.1	0.0	0.0	0.0	0.0	3.39	0.07	CSX Corp. Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	618.0	0.0	0.0	0.0	0.0	7.07	0.35	
New Boston	MA	New Castle, PA	0.0	0.0	0.0	0.0	0.0	486.0	12.96	1.83	Conrail Perth Amboy, NJ Collier
New Boston	MA	Uniontown, PA	0.0	0.0	0.0	0.0	1134.0	0.0	12.09	2.12	CSX Corp. Curtis Bay, MD Collier
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	1134.0	486.0	12.35	2.05	
Mystic	MA	New Castle, PA	0.0	0.0	0.0	0.0	0.0	287.0	12.96	1.88	Conrail Perth Amboy, NJ Collier
Mystic	MA	Uniontown, PA	0.0	0.0	0.0	0.0	670.0	0.0	12.09	2.12	CSX Corp. Curtis Bay, MD Collier
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	670.0	287.0	12.35	2.05	

Table E.2. (continued)

FUA Plant	State	Coal Source	Annual Demand by Coal Type (% Sulfur) (Kilotons) 0.00-0.64%	0.65-1.04%	1.05-1.84%	1.85-2.24%	2.25-3.04%	3.05 +%	Transport Cost ($/ton)	Delay Cost ($/ton)	Carriers
Canal	MA	New Castle, PA	0.0	0.0	0.0	0.0	0.0	318.0	12.69	1.77	Conrail Perth Amboy, NJ Collier
Canal	MA	Uniontown, PA	0.0	0.0	0.0	0.0	741.0	0.0	11.82	2.02	CSX Corp. Curtis Bay, MD Collier
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	741.0	318.0	12.08	1.95	
Mount Tom	MA	State College, PA	0.0	0.0	0.0	0.0	200.0	0.0	11.37	0.74	Conrail Power Plant RR Link
Mount Tom	MA	New Castle, PA	0.0	0.0	0.0	0.0	0.0	85.0	13.07	0.76	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	200.0	85.0	11.87	0.74	
Salem Harbor	MA	State College, PA	0.0	0.0	0.0	0.0	432.6	0.0	10.37	1.63	Conrail Perth Amboy, NJ Collier
Salem Harbor	MA	New Castle, PA	0.0	0.0	0.0	0.0	0.0	207.0	12.97	1.88	Conrail Perth Amboy, NJ Collier
Salem Harbor	MA	Uniontown, PA	0.0	0.0	0.0	0.0	49.4	0.0	12.10	2.12	CSX Corp. Curtis Bay, MD Collier
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	482.0	207.0	11.28	1.74	
Somerset	MA	New Castle, PA	0.0	0.0	0.0	0.0	0.0	74.0	12.40	1.67	Conrail Perth Amboy, NJ Collier
Somerset	MA	Johnstown, PA	0.0	0.0	0.0	0.0	174.0	0.0	10.77	1.27	Conrail Perth Amboy, NJ Collier
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	174.0	74.0	11.26	1.39	
West Springfield	MA	State College, PA	0.0	0.0	0.0	0.0	159.0	0.0	11.41	0.74	Conrail Power Plant RR Link

Table E.2. (continued)

FUA Plant	State	Coal Source	Annual Demand by Coal Type (% Sulfur) (Kilotons) 0.00-0.64%	0.65-1.04%	1.05-1.84%	1.85-2.24%	2.25-3.04%	3.05 +%	Transport Cost ($/ton)	Delay Cost ($/ton)	Carriers
West Springfield	MA	New Castle, PA	0.0	0.0	0.0	0.0	0.0	68.0	13.11	0.76	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	159.0	68.0	11.91	0.75	
Schiller	NH	New Castle, PA	0.0	0.0	0.0	44.2	0.0	0.0	13.18	1.96	Conrail Perth Amboy, NJ Collier
Schiller	NH	Pittsburgh, PA	0.0	0.0	0.0	361.8	0.0	0.0	14.42	2.06	Conrail Perth Amboy, NJ Collier
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	406.0	0.0	0.0	14.28	2.05	
Deepwater	NJ	Uniontown, PA	0.0	0.0	0.0	0.0	463.0	0.0	8.83	0.84	CSX Corp. Curtis Bay, MD Intercoastal Barge
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	463.0	0.0	8.83	0.84	
Sayreville	NJ	Johnstown, PA	0.0	0.0	0.0	0.0	522.0	0.0	8.16	0.43	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	522.0	0.0	8.16	0.43	
Bergen	NJ	State College, PA	0.0	0.0	0.0	0.0	745.7	0.0	7.54	0.44	Conrail Power Plant RR Link
Bergen	NJ	Johnstown, PA	0.0	0.0	0.0	0.0	393.3	0.0	8.50	0.45	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	1139.0	0.0	7.87	0.44	
Kearny	NJ	State College, PA	0.0	0.0	0.0	0.0	48.5	0.0	7.54	0.44	Conrail Power Plant RR Link
Kearny	NJ	Johnstown, PA	0.0	0.0	0.0	0.0	475.5	0.0	8.50	0.45	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	524.0	0.0	8.41	0.44	
Sewaren	NJ	Johnstown, PA	0.0	0.0	0.0	0.0	1107.0	0.0	8.14	0.43	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	1107.0	0.0	8.14	0.43	

Table E.2. (continued)

FUA Plant	State	Coal Source	Annual Demand by Coal Type (% Sulfur) (Kilotons) 0.00-0.64%	0.65-1.04%	1.05-1.84%	1.85-2.24%	2.25-3.04%	3.05+%	Transport Cost ($/ton)	Delay Cost ($/ton)	Carriers
Hudson	NJ	State College, PA	0.0	0.0	0.0	0.0	801.0	0.0	7.54	0.44	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	801.0	0.0	7.54	0.44	
Burlington	NJ	State College, PA	0.0	0.0	0.0	0.0	351.0	0.0	6.73	0.50	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	351.0	0.0	6.73	0.50	
Danskammer	NY	New Castle, PA	0.0	0.0	0.0	0.0	0.0	1134.0	11.57	1.31	Conrail Perth Amboy, NJ Intercoastal Barge
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	0.0	1134.0	11.57	1.31	
Arthur Kill	NY	New Castle, PA	0.0	0.0	0.0	1801.2	0.0	0.0	11.01	0.97	Conrail Perth Amboy, NJ Intercoastal Barge
Arthur Kill	NY	Pittsburgh, PA	0.0	0.0	0.0	114.8	0.0	0.0	12.25	1.07	Conrail Perth Amboy, NJ Intercoastal Barge
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	1916.0	0.0	0.0	11.09	0.98	
Ravenswood	NY	Pittsburgh, PA	0.0	0.0	0.0	1680.0	0.0	0.0	12.41	1.17	Conrail Perth Amboy, NJ Intercoastal Barge
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	1680.0	0.0	0.0	12.41	1.17	
Barrett, E.F.	NY	State College, PA	0.0	0.0	0.0	0.0	796.9	0.0	8.67	0.88	Conrail Perth Amboy, NJ Intercoastal Barge
Barrett, E.F.	NY	Johnstown, PA	0.0	0.0	0.0	0.0	21.1	0.0	9.64	0.74	Conrail Perth Amboy, NJ Intercoastal Barge
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	818.0	0.0	8.70	0.88	
Northport	NY	New Castle, PA	0.0	0.0	0.0	2663.0	0.0	941.0	11.38	1.20	Conrail Perth Amboy, NJ Intercoastal Barge
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	2663.0	0.0	941.0	11.38	1.20	

Table E.2. (continued)

FUA Plant	State	Coal Source	Annual Demand by Coal Type (% Sulfur) (Kilotons) 0.00-0.64%	0.65-1.04%	1.05-1.84%	1.85-2.24%	2.25-3.04%	3.05 +%	Transport Cost ($/ton)	Delay Cost ($/ton)	Carriers
Far Rockaway	NY	State College, PA	0.0	0.0	275.0	0.0	0.0	0.0	8.61	0.84	Conrail Perth Amboy, NJ Intercoastal Barge
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	275.0	0.0	0.0	0.0	8.61	0.84	
Glenwood	NY	State College, PA	0.0	0.0	0.0	0.0	673.0	0.0	8.69	0.89	Conrail Perth Amboy, NJ Intercoastal Barge
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	673.0	0.0	8.69	0.89	
Port Jefferson	NY	State College, PA	0.0	0.0	1049.0	0.0	0.0	0.0	8.93	1.03	Conrail Perth Amboy, NJ Intercoastal Barge
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	1049.0	0.0	0.0	0.0	8.93	1.03	
Albany	NY	State College, PA	0.0	0.0	878.0	0.0	0.0	0.0	9.64	0.56	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	878.0	0.0	0.0	0.0	9.64	0.56	
Lovett	NY	State College, PA	0.0	0.0	0.0	0.0	1214.0	0.0	8.34	0.54	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	1214.0	0.0	8.34	0.54	
Oswego	NY	State College, PA	0.0	0.0	992.0	0.0	0.0	0.0	7.00	0.39	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	992.0	0.0	0.0	0.0	7.00	0.39	
Cromby	PA	New Castle, PA	0.0	0.0	0.0	0.0	0.0	424.0	8.83	0.69	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	0.0	424.0	8.83	0.69	
Schuylkill	PA	New Castle, PA	0.0	0.0	0.0	0.0	0.0	374.0	9.87	0.79	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	0.0	374.0	9.87	0.79	
Southwark	PA	New Castle, PA	0.0	0.0	0.0	0.0	0.0	1159.0	9.87	0.79	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	0.0	1159.0	9.87	0.79	

Table E.2. (continued)

FUA Plant	State	Coal Source	Annual Demand by Coal Type (% Sulfur) (Kilotons) 0.00-0.64%	0.65-1.04%	1.05-1.84%	1.85-2.24%	2.25-3.04%	3.05+%	Transport Cost ($/ton)	Delay Cost ($/ton)	Carriers
Springdale	PA	New Castle, PA	0.0	0.0	0.0	0.0	0.0	518.0	2.90	0.02	Conrail Power Plant RR Link
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	0.0	518.0	2.90	0.02	
South Street	RI	New Castle, PA	0.0	0.0	0.0	0.0	0.0	91.0	12.41	1.67	Conrail Perth Amboy, NJ Collier
South Street	RI	Uniontown, PA	0.0	0.0	0.0	0.0	200.0	0.0	11.54	1.91	CSX Corp. Curtis Bay, MD Collier
Plant Totals & Mean Transport & Delay Cost:			0.0	0.0	0.0	0.0	200.0	91.0	11.81	1.84	

APPENDIX F. REPORT WRITER 2

NORTHEAST REGIONAL COAL FLOWS SORTED BY CHANGE IN ARC VOLUME FOR BASE CASE AND FUA CASE

Table F.1. Northeast Regional Coal Flows Sorted by Change in Arc Volume, for Base Case and FUA Case, 1991 Oil SIP

Seq	FNEM Arc LIC Code	FUA - Base (Megatons)	FUA Case Coal Volume (Megatons)	Base Case Coal Volume (Megatons)	Pre-Load Volume (Megatons)	FUA Case Total Volume (Megatons)	FUA Case Volume/ Capacity
1	RDG58	27.797	37.887	10.090	1.100	38.987	0.9769
2	RDG64	27.797	37.887	10.090	1.100	38.987	0.9769
3	RDG73	27.797	37.887	10.090	1.100	38.987	0.9769
4	P0068	25.383	52.855	27.472	33.000	85.855	0.7181
5	P0627	24.599	25.304	0.705	11.000	36.304	0.9097
6	P0791	24.599	25.304	0.705	11.000	36.304	0.9097
7	P0784	24.599	25.304	0.705	33.000	58.304	0.4876
8	P0785	24.599	25.304	0.705	55.000	80.304	0.6716
9	P0090	24.599	25.304	0.705	11.000	36.304	0.9097
10	P0792	24.599	25.304	0.705	11.000	36.304	0.9097
11	P0066	24.423	25.129	0.705	33.000	58.129	0.4862
12	LV024	21.487	22.109	0.622	1.100	23.209	0.5816
13	TRS91	19.858	20.480	0.622	0.0	20.480	0.0205
14	RDG49	16.623	40.558	23.935	1.100	41.658	1.0439
15	RDG41	15.995	43.467	27.472	1.100	44.567	1.1168
16	LV046	15.657	20.482	4.825	11.000	31.482	0.2366
17	LV043	15.657	20.482	4.825	11.000	31.482	0.2366
18	LV045	15.657	20.482	4.825	1.100	21.582	0.5408
19	LV042	15.657	20.482	4.825	11.000	31.482	0.2366
20	LV080	15.657	20.482	4.825	1.100	21.582	0.5408
21	LV027	15.657	18.319	2.662	33.000	51.319	0.3857
22	LV033	15.657	18.319	2.662	55.000	73.319	0.5510
23	LV034	15.657	18.319	2.662	11.000	29.319	0.2203
24	LV038	15.657	18.319	2.662	11.000	29.319	0.2203
25	LV037	15.657	18.319	2.662	1.100	19.419	0.1624
26	CNJ21	15.209	15.209	0.0	5.500	20.709	0.1732
27	CNJ13	15.209	15.209	0.0	5.500	20.709	0.1732
28	CNJ17	15.209	15.209	0.0	5.500	20.709	0.1732
29	RDG70	12.264	15.914	3.650	1.100	17.014	0.4263
30	RDG57	12.264	17.381	5.117	5.500	22.881	0.5734
31	RDG23	11.840	13.776	1.935	1.100	14.876	0.3728
32	P0736	11.840	13.776	1.935	33.000	46.776	1.0585
33	P0056	11.840	13.776	1.935	33.000	46.776	1.0585
34	LV021	11.531	11.531	0.0	1.100	12.631	0.3165
35	LV022	11.531	11.531	0.0	11.000	22.531	0.5646
36	RDG20	11.272	13.208	1.935	33.000	46.208	0.3865
37	RDG06	11.272	13.208	1.935	33.000	46.208	1.1579
38	P1041	9.956	10.578	0.622	33.000	43.578	1.0920
39	P0053	9.956	10.578	0.622	33.000	43.578	0.9862
40	P0052	9.956	10.578	0.622	33.000	43.578	0.9862
41	P0625	9.481	13.131	3.650	33.000	46.131	1.1560
42	P0770	9.388	9.388	0.0	33.000	42.388	0.3545
43	P0636	8.760	8.760	0.0	33.000	41.760	1.0464
44	MPA02	8.760	12.296	3.537	33.000	45.296	0.3788
45	P0624	7.762	9.698	1.935	1.100	10.798	0.2706
46	P0738	7.762	9.698	1.935	1.100	10.798	0.2706
47	BX213	7.448	14.893	7.445	33.000	47.893	0.4006
48	P0762	6.694	10.344	3.650	1.100	11.444	0.2868
49	RDG35	5.570	5.570	0.0	33.000	38.570	0.3226
50	WM013	5.088	5.918	0.830	11.000	16.918	0.4239
51	BX186	4.712	8.943	4.230	55.000	63.943	0.5348
52	BX188	4.712	8.943	4.230	55.000	63.943	0.4805
53	BX185	4.712	8.943	4.230	55.000	63.943	0.4805
54	BX184	4.712	8.943	4.230	55.000	63.943	0.4805
55	RDG16	4.502	4.502	0.0	33.000	37.502	0.3137
56	RDG67	4.502	4.502	0.0	33.000	37.502	0.3137
57	P0113	4.042	15.351	11.308	33.000	48.351	0.4044
58	P0113	4.042	15.351	11.308	33.000	48.351	0.4044
59	WM039	3.804	4.635	0.830	55.000	59.634	0.4988
60	WM024	3.804	4.635	0.830	1.100	5.735	0.1437
61	WM015	3.804	4.635	0.830	22.000	26.634	0.6674
62	P0143	3.724	7.783	4.060	11.000	18.783	0.4707
63	CNJ02	3.678	3.678	0.0	1.100	4.778	0.0400
64	CNJ04	3.678	3.678	0.0	1.100	4.778	0.0400
65	CNJ09	3.678	3.678	0.0	5.500	9.178	0.0768
66	BX187	3.665	6.460	2.795	55.000	61.460	0.4619
67	BX249	3.665	6.460	2.795	55.000	61.460	0.5140
68	WX068	3.604	3.604	0.0	0.0	3.604	0.0
69	TRS04	3.492	3.498	0.006	0.0	3.498	0.0257
70	P0083	3.405	4.984	1.579	1.100	6.084	0.1525

Table F.1. (continued)

Seq	FNEM Arc LIC Code	FUA - Base (Megatons)	FUA Case Coal Volume (Megatons)	Base Case Coal Volume (Megatons)	Pre-Load Volume (Megatons)	FUA Case Total Volume (Megatons)	FUA Case Volume/ Capacity
71	WM008	3.392	4.046	0.654	5.500	9.546	0.2392
72	WM008	3.392	4.046	0.654	5.500	9.546	0.2392
73	WM009	3.192	3.434	0.241	1.100	4.534	0.1136
74	WM010	3.192	3.434	0.241	22.000	25.434	0.6373
75	P0834	3.101	4.681	1.579	55.000	59.681	0.4485
76	P0832	3.101	4.681	1.579	55.000	59.681	0.4485
77	P0620	3.101	4.681	1.579	55.000	59.681	0.4485
78	P0831	3.101	4.681	1.579	55.000	59.681	0.4992
79	P1055	3.101	4.681	1.579	55.000	59.681	0.4992
80	P0833	3.101	4.681	1.579	55.000	59.681	0.4992
81	WX167	3.035	3.035	0.0	0.0	3.035	0.0
82	RDG69	2.783	2.783	0.0	1.100	3.883	0.0973
83	LV004	2.713	3.443	0.729	1.100	4.543	0.0380
84	P0612	2.713	3.443	0.729	55.000	58.443	0.4392
85	P0614	2.713	3.443	0.729	55.000	58.443	0.4392
86	P0615	2.713	3.443	0.729	55.000	58.443	0.4392
87	BX126	2.519	4.173	1.654	5.500	9.673	0.2424
88	P0108	2.257	14.879	12.622	5.500	20.379	0.5107
89	WX059	1.916	1.916	0.0	0.0	1.916	0.0
90	P0743	1.884	2.334	0.450	5.500	7.834	0.1963
91	WM005	1.696	2.036	0.340	22.000	24.036	0.6023
92	WX060	1.680	1.680	0.0	0.0	1.680	0.0
93	P0692	1.646	1.654	0.009	1.100	2.754	0.0690
94	P0692	1.646	1.654	0.009	1.100	2.754	0.0690
95	P0693	1.634	3.437	1.803	1.100	4.537	0.1137
96	P0693	1.634	3.437	1.803	1.100	4.537	0.1137
97	WZ047	1.620	1.620	0.0	0.0	1.620	0.0
98	BX032	1.589	1.589	0.0	22.000	23.589	0.1773
99	P0745	1.533	1.983	0.450	5.500	7.483	0.1875
100	P0221	1.513	3.069	1.556	5.500	8.569	0.2147
101	P0195	1.513	3.069	1.556	1.100	4.169	0.1045
102	BX176	1.352	4.960	3.608	55.000	59.960	0.5015
103	BX057	1.352	4.960	3.608	55.000	59.960	0.4506
104	EL068	1.214	1.214	0.0	33.000	34.214	0.8573
105	F0051	1.214	1.214	0.0	55.000	56.214	1.2721
106	WX058	1.134	1.134	0.0	0.0	1.134	0.0
107	P0868	1.107	1.107	0.0	1.100	2.207	0.0553
108	P0177	1.073	4.188	3.115	11.000	15.188	0.1270
109	P0175	1.073	3.985	2.912	1.100	5.085	0.1274
110	P0759	1.073	3.985	2.912	55.000	58.985	0.4433
111	P0755	1.073	3.985	2.912	55.000	58.985	0.4433
112	P0641	1.073	3.985	2.912	55.000	58.985	0.4933
113	P0178	1.073	4.188	3.115	11.000	15.188	0.1270
114	P0640	1.073	3.985	2.912	33.000	36.985	0.1681
115	P0043	1.068	1.789	0.721	55.000	56.789	0.4268
116	P0042	1.068	1.789	0.721	55.000	56.789	0.4268
117	P0042	1.068	1.789	0.721	55.000	56.789	0.4268
118	P0816	1.068	1.789	0.721	55.000	56.789	0.4268
119	P0043	1.068	1.789	0.721	55.000	56.789	0.4268
120	WZ049	1.059	1.059	0.0	0.0	1.059	0.0
121	WX064	1.049	1.049	0.0	0.0	1.049	0.0
122	BX190	1.047	2.483	1.436	1.100	3.583	0.0898
123	P0803	1.018	1.747	0.729	55.000	56.747	0.4265
124	P0810	1.016	1.778	0.763	55.000	56.778	0.4267
125	P0809	1.016	1.778	0.763	55.000	56.778	0.4267
126	P0811	1.016	1.778	0.763	55.000	56.778	1.2849
127	P0813	1.012	2.061	1.048	55.000	57.061	0.4288
128	EL114	0.994	1.472	0.478	22.000	23.472	0.5882
129	P0097	0.994	1.472	0.478	22.000	23.472	0.5882
130	P0630	0.994	1.472	0.478	5.500	6.972	0.1747
131	P0631	0.994	1.472	0.478	1.100	2.572	0.0645
132	P0078	0.985	1.635	0.650	1.100	2.735	0.0685
133	P0080	0.985	1.635	0.650	5.500	7.135	0.1788
134	WZ048	0.957	0.957	0.0	0.0	0.957	0.0
135	BX178	0.908	4.308	3.400	55.000	59.308	0.4457
136	BX180	0.908	4.308	3.400	55.000	59.308	0.4457
137	BX183	0.908	4.308	3.400	55.000	59.308	0.4457
138	BX181	0.908	4.308	3.400	55.000	59.308	0.4457
139	BX179	0.908	4.308	3.400	55.000	59.308	0.4457
140	BX226	0.884	0.961	0.077	22.000	22.961	0.5754
141	P0607	0.882	1.468	0.586	1.100	2.568	0.0215
142	P0805	0.881	1.772	0.891	55.000	56.772	0.4266
143	P0929	0.881	1.772	0.891	5.500	7.272	0.0608
144	P0804	0.881	1.772	0.891	55.000	56.772	0.4266
145	P0931	0.881	1.772	0.891	55.000	56.772	0.4266

Table F.1. (continued)

Seq	FNEM Arc LIC Code	FUA - Base (Megatons)	FUA Case Coal Volume (Megatons)	Base Case Coal Volume (Megatons)	Pre-Load Volume (Megatons)	FUA Case Total Volume (Megatons)	FUA Case Volume/ Capacity
146	WX041	0.873	0.873	0.0	0.0	0.873	0.0
147	P1044	0.838	0.838	0.0	33.000	33.838	0.1538
148	WX061	0.818	0.818	0.0	0.0	0.818	0.0
149	WX045	0.817	0.817	0.0	0.0	0.817	0.0
150	BX227	0.789	0.859	0.069	22.000	22.859	0.5728
151	P0629	0.783	1.645	0.862	1.100	2.745	0.0230
152	BX218	0.734	1.074	0.341	22.000	23.074	0.5222
153	BX217	0.734	1.074	0.341	22.000	23.074	0.1734
154	BX212	0.694	1.074	0.380	33.000	34.074	0.2561
155	BX214	0.694	1.074	0.380	33.000	34.074	0.2561
156	BX211	0.694	1.074	0.380	22.000	23.074	0.1930
157	WZ050	0.689	0.689	0.0	0.0	0.689	0.0
158	WX063	0.673	0.673	0.0	0.0	0.673	0.0
159	WX043	0.655	0.655	0.0	0.0	0.655	0.0
160	MGA02	0.623	0.860	0.237	1.100	1.960	0.0444
161	MGA02	0.623	0.860	0.237	1.100	1.960	0.0444
162	P0099	0.610	1.088	0.478	22.000	23.088	0.5785
163	P0749	0.568	0.568	0.0	1.100	1.668	0.0418
164	P0081	0.532	0.853	0.321	5.500	6.353	0.1592
165	MGA02	0.525	0.653	0.129	1.100	1.753	0.0397
166	MGA03	0.525	0.653	0.129	1.100	1.753	0.0397
167	PLE08	0.525	0.653	0.129	22.000	22.653	0.5677
168	CNJ15	0.522	0.522	0.0	1.100	1.622	0.0136
169	P0021	0.518	1.165	0.647	55.000	56.165	0.4698
170	P0021	0.518	1.165	0.647	55.000	56.165	0.4698
171	P0845	0.518	1.182	0.664	55.000	56.182	0.4699
172	P0048	0.518	1.182	0.664	55.000	56.182	0.4699
173	P0884	0.518	1.182	0.664	55.000	56.182	0.4699
174	P0048	0.518	1.182	0.664	55.000	56.182	0.4699
175	P0050	0.511	0.900	0.389	33.000	33.900	0.7671
176	EL146	0.511	0.900	0.389	1.100	2.000	0.0501
177	P0050	0.511	0.900	0.389	33.000	33.900	0.7671
178	P0610	0.511	0.900	0.389	55.000	55.900	0.4675
179	P0848	0.511	0.900	0.389	33.000	33.900	0.7671
180	P0853	0.511	0.900	0.389	33.000	33.900	0.7671
181	LHR02	0.507	1.229	0.722	1.100	2.329	0.0584
182	LHR01	0.507	1.229	0.722	1.100	2.329	0.0584
183	LHR06	0.507	1.229	0.722	1.100	2.329	0.0584
184	EL035	0.506	0.515	0.009	33.000	33.515	0.2803
185	WX177	0.463	0.463	0.0	0.0	0.463	0.0
186	P0079	0.453	0.782	0.330	5.500	6.282	0.1574
187	EL078	0.448	1.863	1.414	1.100	2.963	0.0742
188	EL078	0.448	1.863	1.414	1.100	2.963	0.0742
189	WZ046	0.436	0.436	0.0	0.0	0.436	0.0
190	WX042	0.431	0.431	0.0	0.0	0.431	0.0
191	BX070	0.426	0.460	0.033	22.000	22.460	0.1878
192	EL030	0.419	7.881	7.462	22.000	29.880	0.7487
193	EL019	0.419	7.881	7.462	22.000	29.880	0.2499
194	WZ052	0.406	0.406	0.0	0.0	0.406	0.0
195	EL111	0.385	0.385	0.0	22.000	22.385	0.1872
196	EL103	0.385	0.385	0.0	22.000	22.385	0.1872
197	EL110	0.385	0.385	0.0	22.000	22.385	0.1872
198	EL113	0.385	0.385	0.0	22.000	22.385	0.5609
199	EL148	0.379	1.317	0.938	1.100	2.417	0.0606
200	P0128	0.354	0.354	0.0	11.000	11.354	0.2845
201	P0120	0.354	0.354	0.0	33.000	33.354	0.2507
202	P0132	0.354	0.354	0.0	11.000	11.354	0.2845
203	P0134	0.354	0.354	0.0	33.000	33.354	0.2790
204	P0129	0.354	0.354	0.0	11.000	11.354	0.2845
205	P0139	0.354	0.354	0.0	11.000	11.354	0.2845
206	WZ067	0.291	0.291	0.0	0.0	0.291	0.0
207	BX051	0.288	0.288	0.0	22.000	22.288	0.5585
208	P0589	0.285	0.285	0.0	1.100	1.385	0.0347
209	WX062	0.275	0.275	0.0	0.0	0.275	0.0
210	BX083	0.262	0.357	0.095	11.000	11.357	0.2570
211	BX071	0.262	0.357	0.095	11.000	11.357	0.2570
212	WZ051	0.248	0.248	0.0	0.0	0.248	0.0
213	P0887	0.233	0.711	0.478	55.000	55.711	0.4187
214	WX044	0.227	0.227	0.0	0.0	0.227	0.0
215	P0131	0.185	0.185	0.0	11.000	11.185	0.2803
216	LV059	0.183	0.434	0.252	22.000	22.434	0.1686
217	YS002	0.181	0.261	0.081	1.100	1.361	0.0341

Table F.1. (continued)

Seq	FNEM Arc LIC Code	FUA - Base (Megatons)	FUA Case Coal Volume (Megatons)	Base Case Coal Volume (Megatons)	Pre-Load Volume (Megatons)	FUA Case Total Volume (Megatons)	FUA Case Volume/ Capacity
218	P0786	0.176	0.176	0.0	11.000	11.176	0.2800
219	P0130	0.169	0.169	0.0	11.000	11.169	0.2799
220	P0672	0.157	0.289	0.132	33.000	33.289	0.2784
221	P0154	0.146	0.295	0.149	11.000	11.295	0.2830
222	EL021	0.134	2.300	2.167	11.000	13.300	0.1112
223	EL027	0.134	2.300	2.167	22.000	24.300	0.2032
224	EL023	0.134	2.300	2.167	11.000	13.300	0.1112
225	EL143	0.134	2.300	2.167	22.000	24.300	0.2032
226	EL020	0.134	2.300	2.167	22.000	24.300	0.2032
227	EL025	0.134	2.300	2.167	22.000	24.300	0.2032
228	EL028	0.134	2.300	2.167	11.000	13.300	0.1112
229	P0197	0.121	0.369	0.247	5.500	5.869	0.1471
230	P0220	0.121	0.369	0.247	5.500	5.869	0.1471
231	EL032	0.107	1.994	1.886	33.000	34.994	0.2927
232	LV012	0.107	1.994	1.886	1.100	3.094	0.0775
233	EL145	0.107	1.994	1.886	33.000	34.994	0.2927
234	BX062	0.101	5.476	5.375	55.000	60.476	0.5058
235	EL104	0.097	3.901	3.803	22.000	25.901	0.6490
236	LV060	0.058	0.293	0.235	22.000	22.293	0.1675
237	EL092	0.058	0.293	0.235	5.500	5.793	0.0485
238	EL094	0.058	0.293	0.235	5.500	5.793	0.0485
239	EL079	0.058	0.293	0.235	5.500	5.793	0.1452
240	EL093	0.058	0.293	0.235	1.100	1.393	0.0117
241	EL079	0.058	0.293	0.235	5.500	5.793	0.1452
242	EL094	0.058	0.293	0.235	5.500	5.793	0.1452
243	EL101	0.058	0.293	0.235	1.100	1.393	0.0117
244	BX230	0.056	0.058	0.002	11.000	11.058	0.2771
245	BX069	0.026	0.103	0.077	22.000	22.103	0.1849
246	P0264	0.013	0.026	0.013	33.000	33.026	0.2482
247	P0265	0.013	0.026	0.013	33.000	33.026	0.2482
248	PLE12	0.008	0.013	0.006	22.000	22.013	0.5516
249	PLE12	0.008	0.013	0.006	22.000	22.013	0.5516
250	P0023	0.006	0.465	0.459	33.000	33.465	0.2515
251	P0591	0.006	0.484	0.478	33.000	33.484	0.2516
252	P0023	0.006	0.465	0.459	33.000	33.465	0.2515
253	P0890	0.006	0.484	0.478	33.000	33.484	0.2516
254	P0889	0.006	0.484	0.478	33.000	33.484	0.2516
255	P0022	0.006	0.465	0.459	33.000	33.465	0.7573
256	P0022	0.006	0.465	0.459	33.000	33.465	0.2515
257	P0155	0.006	0.015	0.009	55.000	55.015	0.4134
258	P0157	0.006	0.015	0.009	55.000	55.015	0.4134
259	P0609	0.004	0.590	0.586	1.100	1.690	0.0141
260	P0008	0.0	0.453	0.453	5.500	5.953	0.1492
261	VTR04	0.0	0.145	0.145	1.100	1.245	0.0312
262	P0005	0.0	0.453	0.453	5.500	5.953	0.1492
263	LV058	0.0	0.000	0.000	11.000	11.000	0.2489
264	MEC28	0.0	0.581	0.581	33.000	33.581	0.8415
265	P0176	0.0	0.203	0.203	11.000	11.203	0.0937
266	BM027	0.0	0.017	0.017	1.100	1.117	0.0280
267	CX011	0.0	0.0	0.000	55.000	55.000	0.4133
268	BX120	0.0	0.0	0.000	55.000	55.000	0.4600
269	P0005	0.0	0.453	0.453	5.500	5.953	0.1492
270	LV035	0.0	1.247	1.247	11.000	12.247	0.2772
271	DH010	0.0	0.304	0.305	22.000	22.304	0.5589
272	DH011	0.0	0.304	0.305	22.000	22.304	0.5589
273	DH009	0.0	0.290	0.290	11.000	11.290	0.2829
274	CX001	0.0	0.0	0.000	55.000	55.000	0.4133
275	CLP02	0.0	0.145	0.145	1.100	1.245	0.0312
276	WZ382	0.0	0.581	0.581	0.0	0.581	0.0
277	WY380	0.0	0.041	0.041	0.0	0.041	0.0
278	PRS11	0.0	0.409	0.409	1.100	1.509	0.0378
279	PTM01	0.0	0.581	0.581	5.500	6.081	0.1524
280	BX262	0.0	0.0	0.000	22.000	22.000	0.4979
281	BX231	0.0	0.003	0.003	11.000	11.003	0.2757
282	LV057	0.0	0.000	0.000	11.000	11.000	0.0827
283	BX302	0.0	0.0	0.000	11.000	11.000	0.2756
284	TRS21	0.0	0.041	0.041	0.0	0.041	0.0041
285	BX234	0.0	0.003	0.003	5.500	5.503	0.1379
286	CV018	0.0	0.290	0.290	5.500	5.790	0.1451
287	P0019	0.0	0.453	0.453	5.500	5.953	0.1492
288	P0019	0.0	0.453	0.453	5.500	5.953	0.1492
289	CX224	0.0	0.0	0.000	55.000	55.000	0.4133

Table F.1. (continued)

Seq	FNEM Arc LIC Code	FUA - Base (Megatons)	FUA Case Coal Volume (Megatons)	Base Case Coal Volume (Megatons)	Pre-Load Volume (Megatons)	FUA Case Total Volume (Megatons)	FUA Case Volume/ Capacity
290	MEC22	0.0	0.581	0.531	11.000	11.581	0.2902
291	GTE05	0.0	0.581	0.531	1.100	1.681	0.0421
292	XX001	0.0	0.581	0.531	33.000	33.581	0.7599
293	CX221	0.0	0.0	0.000	55.000	55.000	0.4133
294	BX228	0.0	0.270	0.270	22.000	22.270	0.5040
295	P0639	0.0	3.147	3.147	33.000	36.147	0.9053
296	PRS12	0.0	0.409	0.409	5.500	5.909	0.1481
297	BX073	0.0	0.0	0.000	55.000	55.000	0.4133
298	BM034	0.0	0.453	0.453	5.500	5.953	0.1492
299	CX222	0.0	0.0	0.000	55.000	55.000	0.4133
300	BM035	0.0	0.453	0.453	5.500	5.953	0.0498
301	BX094	0.0	0.000	0.000	22.000	22.000	0.1653
302	VTR06	0.0	0.290	0.290	5.500	5.790	0.1451
303	BX264	0.0	0.0	0.000	55.000	55.000	0.4133
304	BM065	0.0	0.017	0.017	11.000	11.017	0.2761
305	BX076	0.0	0.0	0.000	55.000	55.000	0.4133
306	BX266	0.0	0.0	0.000	55.000	55.000	0.4133
307	VTR03	0.0	0.145	0.145	1.100	1.245	0.0312
308	DH034	0.0	0.304	0.305	22.000	22.304	0.5589
309	LV055	0.0	0.000	0.000	1.100	1.100	0.0249
310	BM058	0.0	0.453	0.453	33.000	33.453	0.7570
311	PRS03	0.0	0.041	0.041	1.100	1.141	0.0286
312	PRS15	0.0	0.041	0.041	1.100	1.141	0.0286
313	BM057	0.0	0.453	0.453	33.000	33.453	0.2514
314	BM061	0.0	0.453	0.453	33.000	33.453	0.2514
315	LV040	0.0	0.000	0.000	1.100	1.100	0.0276
316	P0200	0.0	3.147	3.147	11.000	14.147	0.3545
317	P0214	0.0	1.478	1.478	1.100	2.578	0.0646
318	P0203	0.0	1.669	1.669	11.000	12.669	0.3175
319	BX257	0.0	0.0	0.000	55.000	55.000	0.4600
320	GTE05	0.0	0.581	0.581	1.100	1.681	0.0421
321	MEC21	0.0	0.581	0.581	11.000	11.581	0.2621
322	P0167	0.0	0.187	0.187	55.000	55.187	0.2508
323	BM068	0.0	0.017	0.017	33.000	33.017	0.7472
324	DH008	0.0	0.290	0.290	5.500	5.790	0.1451
325	PRS10	0.0	0.409	0.409	5.500	5.909	0.0494
326	TRS23	0.0	0.581	0.581	0.0	0.581	0.0581
327	PRS11	0.0	0.409	0.409	1.100	1.509	0.0378
328	BX118	0.0	0.0	0.000	11.000	11.000	0.2489
329	PTM03	0.0	0.581	0.581	1.100	1.681	0.0421
330	XX001	0.0	0.581	0.581	33.000	33.581	0.2524
331	BX073	0.0	0.0	0.000	55.000	55.000	0.4133
332	BX231	0.0	0.003	0.003	11.000	11.003	0.2757
333	BX092	0.0	0.000	0.000	22.000	22.000	0.4979
334	CX223	0.0	0.0	0.000	55.000	55.000	0.4133
335	P0885	0.0	0.017	0.017	1.100	1.117	0.0280
336	DH003	0.0	0.290	0.290	5.500	5.790	0.1451
337	CLP01	0.0	0.145	0.145	1.100	1.245	0.0312
338	BX119	0.0	0.0	0.000	55.000	55.000	0.4600
339	LV071	0.0	0.000	0.000	22.000	22.000	0.1653
340	BX091	0.0	0.000	0.000	22.000	22.000	0.4979
341	BX090	0.0	0.000	0.000	22.000	22.000	0.4979
342	BX263	0.0	0.0	0.000	55.000	55.000	0.4133
343	BX113	0.0	0.0	0.000	5.500	5.500	0.1378
344	BX122	0.0	0.0	0.000	33.000	33.000	0.2760
345	P0005	0.0	0.453	0.453	5.500	5.953	0.1492
346	BX121	0.0	0.0	0.000	55.000	55.000	0.4600
347	BX116	0.0	0.0	0.000	22.000	22.000	0.4979
348	CX008	0.0	0.0	0.000	55.000	55.000	0.4133
349	EL050	-0.002	0.209	0.212	22.000	22.209	0.1858
350	EL045	-0.002	0.209	0.212	1.100	1.309	0.0328
351	P0812	-0.003	0.282	0.286	22.000	22.282	0.5583
352	P0807	-0.003	0.282	0.286	22.000	22.282	0.5583
353	P0846	-0.004	0.308	0.311	22.000	22.308	0.5590
354	TRS26	-0.006	0.0	0.006	0.0	0.0	0.0
355	WZ444	-0.006	0.0	0.006	0.0	0.0	0.0
356	EL151	-0.008	0.0	0.008	1.100	1.100	0.0276
357	BX054	-0.016	0.205	0.221	22.000	22.205	0.5564
358	BX053	-0.016	0.205	0.221	22.000	22.205	0.5564
359	EL042	-0.022	1.862	1.884	1.100	2.962	0.0742
360	BX210	-0.039	0.0	0.039	22.000	22.000	0.5513
361	BX219	-0.039	0.0	0.039	22.000	22.000	0.5513
362	BX233	-0.039	0.0	0.039	5.500	5.500	0.1378

Table F.1. (continued)

Seq	FNEM Arc LIC Code	FUA - Base (Megatons)	FUA Case Coal Volume (Megatons)	Base Case Coal Volume (Megatons)	Pre-Load Volume (Megatons)	FUA Case Total Volume (Megatons)	FUA Case Volume/ Capacity
363	BX220	-0.039	0.0	0.039	22.000	22.000	0.5513
364	BX219	-0.039	0.0	0.039	22.000	22.000	0.5513
365	BX204	-0.039	0.0	0.039	11.000	11.000	0.2756
366	BX209	-0.039	0.0	0.039	22.000	22.000	0.5513
367	P0594	-0.050	0.185	0.235	33.000	33.185	0.2775
368	P0594	-0.050	0.185	0.235	33.000	33.185	0.2775
369	EL031	-0.053	4.429	4.481	33.000	37.429	0.3130
370	EL031	-0.053	4.429	4.481	33.000	37.429	0.3130
371	BX229	-0.056	0.216	0.271	22.000	22.216	0.5027
372	BX229	-0.056	0.216	0.271	22.000	22.216	0.5027
373	P0194	-0.062	5.227	5.289	55.000	60.227	0.4526
374	P0223	-0.101	1.455	1.556	33.000	34.454	0.2589
375	P0228	-0.101	1.455	1.556	33.000	34.454	0.2589
376	EL125	-0.118	0.0	0.118	1.100	1.100	0.0276
377	LV050	-0.124	0.024	0.148	1.100	1.124	0.0282
378	LV081	-0.124	0.024	0.148	1.100	1.124	0.0282
379	P0133	-0.129	0.0	0.129	33.000	33.000	0.8269
380	PLE07	-0.129	0.0	0.129	22.000	22.000	0.5513
381	P0121	-0.129	0.0	0.129	1.100	1.100	0.0276
382	P0112	-0.129	0.0	0.129	33.000	33.000	0.2760
383	EL037	-0.135	0.028	0.163	1.100	1.128	0.0283
384	EL037	-0.135	0.028	0.163	1.100	1.128	0.0283
385	EL037	-0.135	0.028	0.163	1.100	1.128	0.0283
386	EL001	-0.137	0.025	0.162	1.100	1.125	0.0282
387	EL002	-0.137	0.025	0.162	1.100	1.125	0.0282
388	P0159	-0.146	1.057	1.203	55.000	56.057	0.4213
389	EL039	-0.157	1.890	2.047	33.000	34.890	0.2918
390	EL038	-0.157	1.890	2.047	1.100	2.990	0.0749
391	EL040	-0.157	1.890	2.047	33.000	34.890	0.2918
392	P0125	-0.157	0.0	0.157	1.100	1.100	0.0276
393	P0127	-0.157	0.0	0.157	55.000	55.000	0.4600
394	P0671	-0.157	0.0	0.157	33.000	33.000	0.2760
395	P0126	-0.157	0.0	0.157	55.000	55.000	0.4600
396	P0123	-0.157	0.0	0.157	55.000	55.000	0.4600
397	P0671	-0.157	0.0	0.157	33.000	33.000	0.2760
398	P0240	-0.157	0.0	0.157	33.000	33.000	0.8269
399	P0237	-0.157	0.0	0.157	33.000	33.000	0.8269
400	P0236	-0.157	0.0	0.157	33.000	33.000	0.8269
401	P0239	-0.157	0.0	0.157	55.000	55.000	0.4133
402	P0644	-0.157	0.0	0.157	33.000	33.000	0.2480
403	P0779	-0.163	10.848	11.011	33.000	43.848	1.0987
404	P0662	-0.205	0.060	0.265	1.100	1.160	0.0291
405	P0662	-0.205	0.060	0.265	1.100	1.160	0.0291
406	BX247	-0.235	0.0	0.235	33.000	33.000	0.8269
407	BX243	-0.235	0.0	0.235	33.000	33.000	0.8269
408	EL116	-0.235	0.0	0.235	11.000	11.000	0.2756
409	P0651	-0.262	0.026	0.288	55.000	55.026	0.4135
410	P0303	-0.262	0.0	0.262	1.100	1.100	0.0276
411	P0652	-0.262	0.0	0.262	55.000	55.000	0.4600
412	P0695	-0.262	0.0	0.262	1.100	1.100	0.0276
413	P0269	-0.262	0.0	0.262	1.100	1.100	0.0276
414	P0655	-0.262	0.0	0.262	1.100	1.100	0.0276
415	P0267	-0.262	0.0	0.262	11.000	11.000	0.2756
416	LV084	-0.268	0.225	0.493	11.000	11.225	0.2540
417	P0247	-0.274	0.0	0.274	1.100	1.100	0.0276
418	EL109	-0.281	1.590	1.870	22.000	23.589	0.5911
419	P0646	-0.393	0.0	0.393	1.100	1.100	0.0276
420	EL154	-0.393	0.0	0.393	11.000	11.000	0.2756
421	P0617	-0.420	1.468	1.888	33.000	34.468	0.8637
422	P0827	-0.423	1.697	2.120	33.000	34.697	0.8694
423	P0618	-0.423	1.697	2.120	33.000	34.697	0.8694
424	EL108	-0.466	1.458	1.924	22.000	23.458	0.5878
425	P0839	-0.735	1.750	2.484	11.000	12.750	0.3195
426	P0041	-0.735	1.750	2.484	1.100	2.850	0.0714
427	P0841	-0.735	1.750	2.484	22.000	23.750	0.5951
428	P0842	-0.735	1.750	2.484	22.000	23.750	0.5951
429	P0183	-0.880	5.656	6.537	55.000	60.656	0.4558
430	BX058	-0.892	8.915	9.808	55.000	63.915	0.4803
431	BX058	-0.892	8.915	9.808	55.000	63.915	0.4803
432	P0642	-1.013	0.0	1.013	1.100	1.100	0.0276
433	P0768	-1.134	3.228	4.362	22.000	25.228	0.6322
434	P0767	-1.219	3.115	4.334	22.000	25.115	0.6293
435	P0058	-1.219	3.115	4.334	22.000	25.115	0.6293

Table F.1. (concluded)

Seq	FNEM Arc LIC Code	FUA - Base (Megatons)	FUA Case Coal Volume (Megatons)	Base Case Coal Volume (Megatons)	Pre-Load Volume (Megatons)	FUA Case Total Volume (Megatons)	FUA Case Volume/ Capacity
436	P0058	-1.219	3.115	4.334	22.000	25.115	0.6293
437	P0067	-1.219	3.196	4.415	11.000	14.196	0.3557
438	BX043	-1.367	6.695	8.062	55.000	61.695	0.4636
439	BX046	-1.367	6.695	8.062	55.000	61.695	0.4636
440	BX042	-1.367	6.695	8.062	55.000	61.695	0.4636
441	BX044	-1.367	6.695	8.062	55.000	61.695	0.4636
442	BX243	-1.367	6.695	8.062	55.000	61.695	0.4636
443	P0109	-1.441	0.063	1.504	55.000	55.063	0.4138
444	P0116	-1.441	0.063	1.504	11.000	11.063	0.2772
445	P0140	-1.441	0.063	1.504	11.000	11.063	0.2772
446	P0110	-1.441	0.063	1.504	11.000	11.063	0.2772
447	P0117	-1.441	0.063	1.504	11.000	11.063	0.2504
448	P0174	-1.450	1.429	2.879	22.000	23.429	0.5871
449	P0182	-1.450	1.429	2.879	22.000	23.429	0.5871
450	P0181	-1.534	5.189	6.723	55.000	60.189	0.4523
451	RDG43	-1.976	0.0	1.976	33.000	33.000	0.2760
452	RDG42	-1.976	0.0	1.976	33.000	33.000	0.2760
453	RDG42	-1.976	0.0	1.976	33.000	33.000	0.2760
454	BX035	-2.191	2.775	4.966	55.000	57.775	0.4342
455	P0634	-2.414	11.431	13.845	33.000	44.431	0.2019
456	P0189	-2.414	11.431	13.845	33.000	44.431	1.1134
457	P0188	-2.414	11.431	13.845	33.000	44.431	1.1134
458	P0179	-2.414	10.845	13.259	33.000	43.845	1.0987
459	CI002	-2.761	3.451	6.213	1.100	4.551	0.1141
460	WM018	-2.828	3.537	6.366	1.100	4.637	0.1162
461	BX059	-2.828	3.537	6.366	33.000	36.537	0.9155
462	WM019	-2.828	3.537	6.366	1.100	4.637	0.1162
463	BX189	-2.828	3.537	6.366	1.100	4.637	0.1162
464	WM026	-3.306	1.878	5.184	11.000	12.878	0.1077
465	P0171	-3.426	1.429	4.856	22.000	23.429	0.5871
466	P0173	-3.426	1.429	4.856	22.000	23.429	0.5871
467	P0169	-3.426	1.429	4.856	22.000	23.429	0.5871
468	P0224	-3.426	1.429	4.856	22.000	23.429	0.5871
469	BX030	-3.450	1.516	4.966	22.000	23.516	0.1967
470	BX033	-3.450	1.516	4.966	5.500	7.016	0.0587
471	BX034	-3.615	1.351	4.966	55.000	56.351	0.4235
472	WM040	-3.875	1.054	4.930	1.100	2.154	0.0180
473	WM026	-3.875	1.054	4.930	11.000	12.054	0.1008
474	LEF02	-8.754	3.497	12.251	1.100	4.597	0.1152

Table F.2. Northeast Regional Coal Flows Sorted by Change in Arc Volume, for Base Case and FUA Case, 1991 NSPS

Seq	FNEM Arc LIC Code	FUA - Base (Megatons)	FUA Case Coal Volume (Megatons)	Base Case Coal Volume (Megatons)	Pre-Load Volume (Megatons)	FUA Case Total Volume (Megatons)	FUA Case Volume/ Capacity
1	RDG73	22.124	32.213	10.090	1.100	33.313	0.8348
2	RDG58	22.124	32.213	10.090	1.100	33.313	0.8348
3	RDG64	22.124	32.213	10.090	1.100	33.313	0.8348
4	P0792	19.363	20.069	0.705	11.000	31.069	0.7785
5	P0785	19.363	20.069	0.705	55.000	75.068	0.6279
6	P0627	19.363	20.069	0.705	11.000	31.069	0.7785
7	P0791	19.363	20.069	0.705	11.000	31.069	0.7785
8	P0784	19.363	20.069	0.705	33.000	53.068	0.4439
9	P0066	19.160	19.866	0.705	33.000	52.866	0.4422
10	LV024	18.683	19.304	0.622	1.100	20.404	0.5113
11	TRS91	17.053	17.675	0.622	0.0	17.675	0.0177
12	P0090	14.905	15.611	0.705	11.000	26.611	0.6668
13	BX186	12.747	16.978	4.230	55.000	71.978	0.6020
14	BX188	12.747	16.978	4.230	55.000	71.978	0.5409
15	BX184	12.747	16.978	4.230	55.000	71.978	0.5409
16	BX185	12.747	16.978	4.230	55.000	71.978	0.5409
17	RDG41	12.723	40.194	27.472	1.100	41.294	1.0348
18	P0068	12.723	40.194	27.472	33.000	73.194	0.6122
19	RDG49	12.723	36.658	23.935	1.100	37.758	0.9461
20	LV033	12.382	15.044	2.662	55.000	70.044	0.5264
21	LV034	12.382	15.044	2.662	11.000	26.044	0.1957
22	LV038	12.382	15.044	2.662	11.000	26.044	0.1957
23	LV037	12.382	15.044	2.662	1.100	16.144	0.1350
24	LV027	12.382	15.044	2.662	33.000	48.044	0.3610
25	LV043	12.373	17.198	4.825	11.000	28.198	0.2119
26	LV045	12.373	17.198	4.825	1.100	18.298	0.4585
27	LV042	12.373	17.198	4.825	11.000	28.198	0.2119
28	LV080	12.373	17.198	4.825	1.100	18.298	0.4585
29	LV046	12.373	17.198	4.825	11.000	28.198	0.2119
30	RDG23	12.274	14.209	1.935	1.100	15.309	0.3836
31	P0056	12.274	14.209	1.935	33.000	47.209	1.0683
32	P0736	12.274	14.209	1.935	33.000	47.209	1.0683
33	BX249	12.073	14.868	2.795	55.000	69.868	0.5844
34	BX187	12.073	14.868	2.795	55.000	69.868	0.5251
35	CNJ13	11.971	11.971	0.0	5.500	17.471	0.1461
36	CNJ17	11.971	11.971	0.0	5.500	17.471	0.1461
37	CNJ21	11.971	11.971	0.0	5.500	17.471	0.1461
38	P0108	11.735	24.357	12.622	5.500	29.857	0.7482
39	BX243	11.211	19.273	8.062	55.000	74.273	0.5582
40	BX044	11.211	19.273	8.062	55.000	74.273	0.5582
41	BX046	11.211	19.273	8.062	55.000	74.273	0.5582
42	WM024	10.982	11.813	0.830	1.100	12.913	0.3236
43	WM015	10.982	11.813	0.830	22.000	33.813	0.8473
44	WM039	10.982	11.813	0.830	55.000	66.813	0.5588
45	WM013	10.982	11.813	0.830	11.000	22.813	0.5716
46	BX058	10.650	20.457	9.808	55.000	75.457	0.5671
47	BX058	10.650	20.457	9.808	55.000	75.457	0.5671
48	P0052	10.390	11.012	0.622	33.000	44.012	0.9960
49	P1041	10.390	11.012	0.622	33.000	44.012	1.1028
50	P0053	10.390	11.012	0.622	33.000	44.012	0.9960
51	WM008	10.277	10.931	0.654	5.500	16.431	0.4117
52	WM008	10.277	10.931	0.654	5.500	16.431	0.4117
53	WM010	9.822	10.064	0.241	22.000	32.064	0.8035
54	WM009	9.822	10.064	0.241	1.100	11.164	0.2797
55	RDG70	9.779	13.429	3.650	1.100	14.529	0.3641
56	RDG57	9.779	14.896	5.117	5.500	20.396	0.5111
57	LV021	9.162	9.162	0.0	1.100	10.262	0.2571
58	LV022	9.162	9.162	0.0	11.000	20.162	0.5052
59	RDG06	8.280	10.215	1.935	33.000	43.215	1.0829
60	RDG20	8.280	10.215	1.935	33.000	43.215	0.3614
61	P0624	8.107	10.042	1.935	1.100	11.142	0.2792
62	P0738	8.107	10.042	1.935	1.100	11.142	0.2792
63	P0625	7.700	11.349	3.650	33.000	44.349	1.1113
64	P0762	7.101	10.751	3.650	1.100	11.851	0.2970
65	TRS04	6.677	6.683	0.006	0.0	6.683	0.0491
66	BX043	6.229	14.292	8.062	55.000	69.292	0.5207
67	BX042	6.229	14.292	8.062	55.000	69.292	0.5207
68	BX213	6.082	13.527	7.445	33.000	46.527	0.3891
69	WM001	4.982	4.982	0.0	5.500	10.482	0.0877
70	P0095	4.458	4.458	0.0	5.500	9.958	0.2495

Table F.2. (continued)

Seq	FNEM Arc LIC Code	FUA - Base (Megatons)	FUA Case Coal Volume (Megatons)	Base Case Coal Volume (Megatons)	Pre-Load Volume (Megatons)	FUA Case Total Volume (Megatons)	FUA Case Volume/ Capacity
71	P0094	4.458	4.458	0.0	5.500	9.958	0.2495
72	P0087	4.458	4.458	0.0	5.500	9.958	0.2495
73	P0088	4.458	4.458	0.0	11.000	15.458	0.3873
74	P0796	4.458	4.458	0.0	5.500	9.958	0.2495
75	P0087	4.458	4.458	0.0	5.500	9.958	0.2495
76	WX068	3.604	3.604	0.0	0.0	3.604	0.0
77	BX248	3.164	3.399	0.235	33.000	36.399	0.9121
78	BX247	3.164	3.399	0.235	33.000	36.399	0.9121
79	P0630	3.058	3.537	0.478	5.500	9.037	0.2264
80	P0097	3.058	3.537	0.478	22.000	25.536	0.6399
81	EL114	3.058	3.537	0.478	22.000	25.536	0.6399
82	P0631	3.058	3.537	0.478	1.100	4.637	0.1162
83	WX167	3.035	3.035	0.0	0.0	3.035	0.0
84	P0629	3.000	3.862	0.862	1.100	4.962	0.0415
85	BX126	2.955	4.609	1.654	5.500	10.109	0.2533
86	P0752	2.919	2.919	0.0	11.000	13.919	0.1164
87	P0757	2.919	2.919	0.0	22.000	24.919	0.2084
88	P0760	2.919	2.919	0.0	22.000	24.919	0.2084
89	P0758	2.919	2.919	0.0	22.000	24.919	0.2084
90	P0176	2.919	3.122	0.203	11.000	14.122	0.1181
91	P0180	2.914	2.914	0.0	55.000	57.914	0.2632
92	P0166	2.914	2.914	0.0	55.000	57.914	0.2632
93	P0167	2.914	3.101	0.187	55.000	58.101	0.2640
94	P0155	2.911	2.920	0.009	55.000	57.920	0.4353
95	P0157	2.911	2.920	0.009	55.000	57.920	0.4353
96	BX057	2.892	6.500	3.608	55.000	61.500	0.4622
97	BX176	2.892	6.500	3.608	55.000	61.500	0.5144
98	CNJ02	2.809	2.809	0.0	1.100	3.909	0.0327
99	CNJ04	2.809	2.809	0.0	1.100	3.909	0.0327
100	CNJ09	2.809	2.809	0.0	5.500	8.309	0.0695
101	P0159	2.736	3.939	1.203	55.000	58.939	0.4429
102	P0739	2.693	2.693	0.0	33.000	35.693	0.8077
103	RDG21	2.693	2.693	0.0	1.100	3.793	0.0950
104	P0740	2.693	2.693	0.0	33.000	35.693	0.8077
105	RDG15	2.693	2.693	0.0	1.100	3.793	0.0950
106	P0735	2.693	2.693	0.0	55.000	57.693	1.3056
107	RDG35	2.678	2.678	0.0	33.000	35.678	0.2934
108	P0099	2.393	2.872	0.478	22.000	24.872	0.6232
109	P0143	2.187	6.246	4.060	11.000	17.246	0.4322
110	P0083	2.170	3.749	1.579	1.100	4.849	0.1215
111	P0620	2.156	3.735	1.579	55.000	58.735	0.4414
112	P0832	2.156	3.735	1.579	55.000	58.735	0.4414
113	P1055	2.156	3.735	1.579	55.000	58.735	0.4912
114	P0834	2.156	3.735	1.579	55.000	58.735	0.4414
115	P0831	2.156	3.735	1.579	55.000	58.735	0.4912
116	P0833	2.156	3.735	1.579	55.000	58.735	0.4912
117	RDG69	2.079	2.079	0.0	1.100	3.179	0.0797
118	WX059	1.916	1.916	0.0	0.0	1.916	0.0
119	RDG16	1.898	1.898	0.0	33.000	34.898	0.2919
120	RDG67	1.898	1.898	0.0	33.000	34.898	0.2919
121	P0743	1.884	2.334	0.450	5.500	7.834	0.1963
122	BX051	1.857	1.857	0.0	22.000	23.857	0.5978
123	BX178	1.765	5.165	3.400	55.000	60.165	0.4521
124	BX181	1.765	5.165	3.400	55.000	60.165	0.4521
125	BX183	1.765	5.165	3.400	55.000	60.165	0.4521
126	BX180	1.765	5.165	3.400	55.000	60.165	0.4521
127	BX179	1.765	5.165	3.400	55.000	60.165	0.4521
128	WX060	1.680	1.680	0.0	0.0	1.680	0.0
129	P0615	1.578	2.308	0.729	55.000	57.308	0.4307
130	P0614	1.578	2.308	0.729	55.000	57.308	0.4307
131	LV004	1.578	2.308	0.729	1.100	3.408	0.0285
132	P0612	1.578	2.308	0.729	55.000	57.308	0.4307
133	P0745	1.533	1.983	0.450	5.500	7.483	0.1875
134	P0692	1.527	1.536	0.009	1.100	2.636	0.0660
135	P0692	1.527	1.536	0.009	1.100	2.636	0.0660
136	BX032	1.485	1.485	0.0	22.000	23.485	0.1765
137	BX062	1.357	6.732	5.375	55.000	61.732	0.5163
138	P0749	1.301	1.301	0.0	1.100	2.401	0.0602
139	MGA02	1.283	1.521	0.237	1.100	2.621	0.0593
140	MGA02	1.283	1.521	0.237	1.100	2.621	0.0593
141	P0051	1.214	1.214	0.0	55.000	56.214	1.2721
142	EL068	1.214	1.214	0.0	33.000	34.214	0.8573
143	BX053	1.137	1.359	0.221	22.000	23.359	0.5853
144	WZ171	1.134	1.134	0.0	0.0	1.134	0.0
145	WX058	1.134	1.134	0.0	0.0	1.134	0.0

Table F.2. (continued)

Seq	FNEM Arc LIC Code	FUA - Base (Megatons)	FUA Case Coal Volume (Megatons)	Base Case Coal Volume (Megatons)	Pre-Load Volume (Megatons)	FUA Case Total Volume (Megatons)	FUA Case Volume/ Capacity
146	P0868	1.107	1.107	0.0	1.100	2.207	0.0553
147	LEF02	1.069	13.321	12.251	1.100	14.421	0.3614
148	WX064	1.049	1.049	0.0	0.0	1.049	0.0
149	WX041	0.873	0.873	0.0	0.0	0.873	0.0
150	P0862	0.869	0.869	0.0	33.000	33.869	0.2545
151	P0866	0.869	0.869	0.0	33.000	33.869	0.2545
152	P0863	0.869	0.869	0.0	33.000	33.869	0.2545
153	P0803	0.841	1.570	0.729	55.000	56.570	0.4251
154	P0811	0.840	1.603	0.763	55.000	56.603	1.2809
155	P0810	0.840	1.603	0.763	55.000	56.603	0.4254
156	P0809	0.840	1.603	0.763	55.000	56.603	0.4254
157	P0813	0.838	1.887	1.048	55.000	56.887	0.4275
158	BX245	0.838	0.838	0.0	33.000	33.838	0.8479
159	WX061	0.818	0.818	0.0	0.0	0.818	0.0
160	WX045	0.817	0.817	0.0	0.0	0.817	0.0
161	EL109	0.815	2.685	1.870	22.000	24.685	0.6186
162	WZ173	0.741	0.741	0.0	0.0	0.741	0.0
163	EL104	0.732	4.535	3.803	22.000	26.535	0.6649
164	P0652	0.717	0.982	0.265	1.100	2.082	0.0522
165	P0662	0.717	0.982	0.265	1.100	2.082	0.0522
166	P0607	0.703	1.290	0.586	1.100	2.390	0.0200
167	P0804	0.703	1.594	0.891	55.000	56.594	0.4253
168	P0931	0.703	1.594	0.891	55.000	56.594	0.4253
169	P0929	0.703	1.594	0.891	5.500	7.094	0.0593
170	P0805	0.703	1.594	0.891	55.000	56.594	0.4253
171	BX190	0.674	2.110	1.436	1.100	3.210	0.0804
172	WX063	0.673	0.673	0.0	0.0	0.673	0.0
173	WM005	0.672	1.012	0.340	22.000	23.012	0.5766
174	WZ172	0.670	0.670	0.0	0.0	0.670	0.0
175	EL113	0.665	0.665	0.0	22.000	22.665	0.5679
176	EL103	0.665	0.665	0.0	22.000	22.665	0.1896
177	EL110	0.665	0.665	0.0	22.000	22.665	0.1896
178	EL111	0.665	0.665	0.0	22.000	22.665	0.1896
179	WX043	0.655	0.655	0.0	0.0	0.655	0.0
180	WZ050	0.640	0.640	0.0	0.0	0.640	0.0
181	P0178	0.592	3.707	3.115	11.000	14.707	0.1230
182	P0177	0.592	3.707	3.115	11.000	14.707	0.1230
183	EL035	0.548	0.556	0.009	33.000	33.556	0.2807
184	CNJ15	0.522	0.522	0.0	1.100	1.622	0.0136
185	P0120	0.518	0.518	0.0	33.000	33.518	0.2519
186	EL108	0.515	2.438	1.924	22.000	24.438	0.6124
187	EL019	0.496	7.958	7.462	22.000	29.957	0.2506
188	EL030	0.496	7.958	7.462	22.000	29.957	0.7507
189	WZ047	0.486	0.486	0.0	0.0	0.486	0.0
190	WX177	0.463	0.463	0.0	0.0	0.463	0.0
191	WZ046	0.436	0.436	0.0	0.0	0.436	0.0
192	WX042	0.431	0.431	0.0	0.0	0.431	0.0
193	EL078	0.411	1.826	1.414	1.100	2.926	0.0733
194	EL078	0.411	1.826	1.414	1.100	2.926	0.0733
195	WZ052	0.406	0.406	0.0	0.0	0.406	0.0
196	BX054	0.398	0.620	0.221	22.000	22.620	0.5668
197	TRS28	0.368	0.368	0.0	0.0	0.368	0.0368
198	BM053	0.368	0.368	0.0	1.100	1.468	0.0123
199	BM083	0.368	0.368	0.0	1.100	1.468	0.0368
200	BM047	0.368	0.368	0.0	1.100	1.468	0.0123
201	BM032	0.368	0.368	0.0	33.000	33.368	0.2508
202	WZ446	0.368	0.368	0.0	0.0	0.368	0.0
203	BM045	0.368	0.368	0.0	5.500	5.868	0.0441
204	EL028	0.319	2.486	2.167	11.000	13.486	0.1128
205	EL021	0.319	2.486	2.167	11.000	13.486	0.1128
206	EL023	0.319	2.486	2.167	11.000	13.486	0.1128
207	EL020	0.319	2.486	2.167	22.000	24.486	0.2048
208	EL143	0.319	2.486	2.167	22.000	24.486	0.2048
209	EL027	0.319	2.486	2.167	22.000	24.486	0.2048
210	EL025	0.319	2.486	2.167	22.000	24.486	0.2048
211	WZ049	0.318	0.318	0.0	0.0	0.318	0.0
212	P0853	0.310	0.699	0.389	33.000	33.699	0.7626
213	EL146	0.310	0.699	0.389	1.100	1.799	0.0451
214	P0610	0.310	0.699	0.389	55.000	55.699	0.4659
215	P0050	0.310	0.699	0.389	33.000	33.699	0.7626
216	P0050	0.310	0.699	0.389	33.000	33.699	0.7626
217	P0848	0.310	0.699	0.389	33.000	33.699	0.7626
218	LHR01	0.308	1.030	0.722	1.100	2.130	0.0534

Table F.2. (continued)

Seq	FNEM Arc LIC Code	FUA - Base (Megatons)	FUA Case Coal Volume (Megatons)	Base Case Coal Volume (Megatons)	Pre-Load Volume (Megatons)	FUA Case Total Volume (Megatons)	FUA Case Volume/ Capacity
219	LHR06	0.308	1.030	0.722	1.100	2.130	0.0534
220	LHR02	0.308	1.030	0.722	1.100	2.130	0.0534
221	WZ048	0.287	0.287	0.0	0.0	0.287	0.0
222	P0589	0.285	0.285	0.0	1.100	1.385	0.0347
223	BX056	0.285	0.285	0.0	22.000	22.285	0.5043
224	BX055	0.285	0.285	0.0	22.000	22.285	0.5584
225	WX062	0.275	0.275	0.0	0.0	0.275	0.0
226	WZ051	0.248	0.248	0.0	0.0	0.248	0.0
227	P0041	0.237	2.721	2.484	1.100	3.821	0.0957
228	P0839	0.237	2.721	2.484	11.000	13.721	0.3438
229	P0842	0.237	2.721	2.484	22.000	24.721	0.6195
230	P0841	0.237	2.721	2.484	22.000	24.721	0.6195
231	WX044	0.227	0.227	0.0	0.0	0.227	0.0
232	P0786	0.203	0.203	0.0	11.000	11.203	0.2807
233	WZ199	0.200	0.200	0.0	0.0	0.200	0.0
234	P0154	0.178	0.328	0.149	11.000	11.328	0.2839
235	EL148	0.161	1.099	0.938	1.100	2.199	0.0551
236	RDG65	0.140	0.140	0.0	1.100	1.240	0.0311
237	P0048	0.138	0.801	0.664	55.000	55.801	0.4667
238	P0884	0.138	0.801	0.664	55.000	55.801	0.4667
239	P0845	0.138	0.801	0.664	55.000	55.801	0.4667
240	P0021	0.138	0.784	0.647	55.000	55.784	0.4666
241	P0021	0.138	0.784	0.647	55.000	55.784	0.4666
242	P0048	0.138	0.801	0.664	55.000	55.801	0.4667
243	WZ067	0.091	0.091	0.0	0.0	0.091	0.0
244	P0672	0.075	0.207	0.132	33.000	33.207	0.2777
245	P0043	0.051	0.772	0.721	55.000	55.772	0.4191
246	P0042	0.051	0.772	0.721	55.000	55.772	0.4191
247	P0042	0.051	0.772	0.721	55.000	55.772	0.4191
248	P0043	0.051	0.772	0.721	55.000	55.772	0.4191
249	P0816	0.051	0.772	0.721	55.000	55.772	0.4191
250	WZ174	0.049	0.049	0.0	0.0	0.049	0.0
251	EL116	0.030	0.266	0.235	11.000	11.266	0.2823
252	LV084	0.029	0.522	0.493	11.000	11.522	0.2607
253	P0326	0.019	0.019	0.0	11.000	11.019	0.2761
254	P0309	0.019	0.019	0.0	1.100	1.119	0.0280
255	P0272	0.019	0.019	0.0	55.000	55.019	0.4135
256	P0305	0.019	0.019	0.0	55.000	55.019	0.4135
257	P0304	0.019	0.019	0.0	1.100	1.119	0.0280
258	P0699	0.019	0.019	0.0	1.100	1.119	0.0280
259	BX226	0.017	0.093	0.077	22.000	22.093	0.5536
260	BX069	0.017	0.093	0.077	22.000	22.093	0.1843
261	P0594	0.015	0.249	0.235	33.000	33.249	0.2781
262	P0594	0.015	0.249	0.235	33.000	33.249	0.2781
263	BX227	0.012	0.082	0.069	22.000	22.082	0.5533
264	BX071	0.012	0.107	0.095	11.000	11.107	0.2513
265	BX083	0.012	0.107	0.095	11.000	11.107	0.2513
266	P0307	0.011	0.011	0.0	1.100	1.111	0.0278
267	WZ441	0.010	0.010	0.0	0.0	0.010	0.0
268	P0247	0.010	0.285	0.274	1.100	1.385	0.0347
269	BX230	0.010	0.012	0.002	11.000	11.012	0.2759
270	P0306	0.008	0.008	0.0	1.100	1.108	0.0278
271	P0308	0.008	0.008	0.0	1.100	1.108	0.0278
272	P0651	0.007	0.295	0.288	55.000	55.295	0.4155
273	P0695	0.007	0.269	0.262	1.100	1.369	0.0343
274	P0655	0.007	0.269	0.262	1.100	1.369	0.0343
275	P0652	0.007	0.269	0.262	55.000	55.269	0.4623
276	P0267	0.007	0.269	0.262	11.000	11.269	0.2824
277	P0269	0.007	0.269	0.262	1.100	1.369	0.0343
278	WZ444	0.006	0.012	0.006	0.0	0.012	0.0
279	TRS26	0.006	0.012	0.006	0.0	0.012	0.0012
280	BX233	0.006	0.045	0.039	5.500	5.545	0.1389
281	BX219	0.006	0.045	0.039	22.000	22.045	0.5524
282	BX204	0.006	0.045	0.039	11.000	11.045	0.2768
283	BX219	0.006	0.045	0.039	22.000	22.045	0.5524
284	BX210	0.006	0.045	0.039	22.000	22.045	0.5524
285	BX209	0.006	0.045	0.039	22.000	22.045	0.5524
286	BX220	0.006	0.045	0.039	22.000	22.045	0.5524
287	BX070	0.004	0.037	0.033	22.000	22.037	0.1843
288	EL151	0.001	0.009	0.008	1.100	1.109	0.0278
289	CX222	0.0	0.000	0.000	55.000	55.000	0.4133
290	PRS11	0.0	0.409	0.409	1.100	1.509	0.0378

Table F.2. (continued)

Seq	FNEM Arc LIC Code	FUA - Base (Megatons)	FUA Case Coal Volume (Megatons)	Base Case Coal Volume (Megatons)	Pre-Load Volume (Megatons)	FUA Case Total Volume (Megatons)	FUA Case Volume/ Capacity
291	BX091	0.0	0.000	0.000	22.000	22.000	0.4979
292	MEC22	0.0	0.581	0.581	11.000	11.581	0.2902
293	PRS03	0.0	0.041	0.041	1.100	1.141	0.0286
294	MEC28	0.0	0.581	0.581	33.000	33.581	0.8415
295	BX234	0.0	0.003	0.003	5.500	5.503	0.1379
296	PRS15	0.0	0.041	0.041	1.100	1.141	0.0286
297	TRS21	0.0	0.041	0.041	0.0	0.041	0.0041
298	BX231	0.0	0.003	0.003	11.000	11.003	0.2757
299	BX122	0.0	0.000	0.000	33.000	33.000	0.2760
300	GTE05	0.0	0.581	0.581	1.100	1.681	0.0421
301	XX001	0.0	0.581	0.581	33.000	33.581	0.7599
302	MEC21	0.0	0.581	0.581	11.000	11.581	0.2621
303	BX231	0.0	0.003	0.003	11.000	11.003	0.2757
304	LV057	0.0	0.000	0.000	11.000	11.000	0.0827
305	DH003	0.0	0.290	0.290	5.500	5.790	0.1451
306	CX011	0.0	0.000	0.000	55.000	55.000	0.4133
307	VTR06	0.0	0.290	0.290	5.500	5.790	0.1451
308	DH011	0.0	0.305	0.305	22.000	22.305	0.5589
309	BX263	0.0	0.000	0.000	55.000	55.000	0.4133
310	BM065	0.0	0.017	0.017	11.000	11.017	0.2761
311	P0203	0.0	1.669	1.669	11.000	12.669	0.3175
312	LV058	0.0	0.000	0.000	11.000	11.000	0.2489
313	CX221	0.0	0.000	0.000	55.000	55.000	0.4133
314	BX257	0.0	0.000	0.000	55.000	55.000	0.4600
315	P0200	0.0	3.147	3.147	11.000	14.147	0.3545
316	P0214	0.0	1.478	1.478	1.100	2.578	0.0646
317	LV071	0.0	0.000	0.000	22.000	22.000	0.1653
318	HY380	0.0	0.041	0.041	0.0	0.041	0.0
319	MPA02	0.0	3.537	3.537	33.000	36.537	0.3056
320	BX094	0.0	0.000	0.000	22.000	22.000	0.1653
321	CV018	0.0	0.290	0.290	5.500	5.790	0.1451
322	BX264	0.0	0.000	0.000	55.000	55.000	0.4133
323	BX118	0.0	0.000	0.000	11.000	11.000	0.2489
324	BX262	0.0	0.000	0.000	22.000	22.000	0.4979
325	BX090	0.0	0.000	0.000	22.000	22.000	0.4979
326	DH034	0.0	0.305	0.305	22.000	22.305	0.5589
327	CX001	0.0	0.000	0.000	55.000	55.000	0.4133
328	BX120	0.0	0.000	0.000	55.000	55.000	0.4600
329	PTM03	0.0	0.581	0.581	1.100	1.681	0.0421
330	LV055	0.0	0.000	0.000	1.100	1.100	0.0249
331	BX121	0.0	0.000	0.000	55.000	55.000	0.4600
332	BM027	0.0	0.017	0.017	1.100	1.117	0.0280
333	LV040	0.0	0.000	0.000	1.100	1.100	0.0276
334	BX113	0.0	0.000	0.000	5.500	5.500	0.1378
335	PRS10	0.0	0.409	0.409	5.500	5.909	0.0494
336	LV035	0.0	1.247	1.247	11.000	12.247	0.2772
337	CX223	0.0	0.000	0.000	55.000	55.000	0.4133
338	BX076	0.0	0.000	0.000	55.000	55.000	0.4133
339	CX224	0.0	0.000	0.000	55.000	55.000	0.4133
340	CLP01	0.0	0.145	0.145	1.100	1.245	0.0312
341	DH009	0.0	0.290	0.290	11.000	11.290	0.2829
342	CX008	0.0	0.000	0.000	55.000	55.000	0.4133
343	BX092	0.0	0.000	0.000	22.000	22.000	0.4979
344	BX073	0.0	0.000	0.000	55.000	55.000	0.4133
345	BX302	0.0	0.000	0.000	11.000	11.000	0.2756
346	XX001	0.0	0.581	0.581	33.000	33.581	0.2524
347	P0639	0.0	3.147	3.147	33.000	36.147	0.9058
348	BX116	0.0	0.000	0.000	22.000	22.000	0.4979
349	BX119	0.0	0.000	0.000	55.000	55.000	0.4600
350	VTR04	0.0	0.145	0.145	1.100	1.245	0.0312
351	PRS12	0.0	0.409	0.409	5.500	5.909	0.1481
352	GTE05	0.0	0.581	0.581	1.100	1.681	0.0421
353	BM068	0.0	0.017	0.017	33.000	33.017	0.7472
354	DH010	0.0	0.305	0.305	22.000	22.305	0.5589
355	P0885	0.0	0.017	0.017	1.100	1.117	0.0280
356	TRS23	0.0	0.581	0.581	0.0	0.581	0.0581
357	BX266	0.0	0.000	0.000	55.000	55.000	0.4133
358	BX073	0.0	0.000	0.000	55.000	55.000	0.4133
359	VTR03	0.0	0.145	0.145	1.100	1.245	0.0312
360	DH008	0.0	0.290	0.290	5.500	5.790	0.1451
361	CLP02	0.0	0.145	0.145	1.100	1.245	0.0312
362	PTM01	0.0	0.581	0.581	5.500	6.081	0.1524

Table F.2. (continued)

Seq	FNEM Arc LIC Code	FUA - Base (Megatons)	FUA Case Coal Volume (Megatons)	Base Case Coal Volume (Megatons)	Pre-Load Volume (Megatons)	FUA Case Total Volume (Megatons)	FUA Case Volume/ Capacity
363	PRS11	0.0	0.409	0.409	1.100	1.509	0.0378
364	PLE12	-0.001	0.004	0.006	22.000	22.004	0.5514
365	PLE12	-0.001	0.004	0.006	22.000	22.004	0.5514
366	EL050	-0.001	0.210	0.212	22.000	22.210	0.1858
367	EL045	-0.001	0.210	0.212	1.100	1.310	0.0328
368	P0807	-0.002	0.284	0.286	22.000	22.284	0.5584
369	P0812	-0.002	0.284	0.286	22.000	22.284	0.5584
370	P0846	-0.002	0.309	0.311	22.000	22.309	0.5590
371	P0265	-0.003	0.010	0.013	33.000	33.010	0.2481
372	P0264	-0.003	0.010	0.013	33.000	33.010	0.2481
373	YS002	-0.003	0.078	0.081	1.100	1.178	0.0295
374	EL154	-0.004	0.388	0.393	11.000	11.388	0.2854
375	P0646	-0.004	0.388	0.393	1.100	1.488	0.0373
376	WZ3S2	-0.010	0.571	0.581	0.0	0.571	0.0
377	BX214	-0.011	0.369	0.380	33.000	33.369	0.2508
378	BX211	-0.011	0.369	0.380	22.000	22.369	0.1871
379	BX212	-0.011	0.369	0.380	33.000	33.369	0.2508
380	P0303	-0.012	0.250	0.262	1.100	1.350	0.0338
381	EL042	-0.013	1.871	1.884	1.100	2.971	0.0744
382	EL125	-0.015	0.104	0.118	1.100	1.204	0.0302
383	BX218	-0.017	0.324	0.341	22.000	22.324	0.5052
384	BX217	-0.017	0.324	0.341	22.000	22.324	0.1678
385	BX228	-0.019	0.251	0.270	22.000	22.251	0.5035
386	LV050	-0.029	0.119	0.148	1.100	1.219	0.0306
387	LV081	-0.029	0.119	0.148	1.100	1.219	0.0306
388	BX229	-0.029	0.242	0.271	22.000	22.242	0.5033
389	BX229	-0.029	0.242	0.271	22.000	22.242	0.5033
390	EL031	-0.031	4.450	4.481	33.000	37.450	0.3132
391	EL031	-0.031	4.450	4.481	33.000	37.450	0.3132
392	P0644	-0.035	0.123	0.157	33.000	33.123	0.2489
393	P0239	-0.035	0.123	0.157	55.000	55.123	0.4142
394	P0237	-0.035	0.123	0.157	33.000	33.123	0.8300
395	P0240	-0.035	0.123	0.157	33.000	33.123	0.8300
396	P0236	-0.035	0.123	0.157	33.000	33.123	0.8300
397	LV059	-0.066	0.186	0.252	22.000	22.186	0.1667
398	P0123	-0.075	0.082	0.157	55.000	55.082	0.4607
399	P0671	-0.075	0.082	0.157	33.000	33.082	0.2767
400	P0127	-0.075	0.082	0.157	55.000	55.082	0.4607
401	P0126	-0.075	0.082	0.157	55.000	55.082	0.4607
402	P0125	-0.075	0.082	0.157	1.100	1.182	0.0296
403	P0671	-0.075	0.082	0.157	33.000	33.082	0.2767
404	LV060	-0.095	0.140	0.235	22.000	22.140	0.1664
405	EL101	-0.095	0.140	0.235	1.100	1.240	0.0104
406	EL093	-0.095	0.140	0.235	1.100	1.240	0.0104
407	EL092	-0.095	0.140	0.235	5.500	5.640	0.0472
408	EL094	-0.095	0.140	0.235	5.500	5.640	0.1413
409	EL094	-0.095	0.140	0.235	5.500	5.640	0.0472
410	EL079	-0.104	0.131	0.235	5.500	5.631	0.1411
411	EL079	-0.104	0.131	0.235	5.500	5.631	0.1411
412	MGA03	-0.129	0.0	0.129	1.100	1.100	0.0249
413	MGA02	-0.129	0.0	0.129	1.100	1.100	0.0249
414	PLE07	-0.129	0.0	0.129	22.000	22.000	0.5513
415	PLE08	-0.129	0.0	0.129	22.000	22.000	0.5513
416	P0133	-0.129	0.0	0.129	33.000	33.000	0.8269
417	P0112	-0.129	0.0	0.129	33.000	33.000	0.2760
418	P0121	-0.129	0.0	0.129	1.100	1.100	0.0276
419	P0197	-0.134	0.114	0.247	5.500	5.614	0.1407
420	P0220	-0.134	0.114	0.247	5.500	5.614	0.1407
421	EL037	-0.137	0.026	0.163	1.100	1.126	0.0282
422	EL037	-0.137	0.026	0.163	1.100	1.126	0.0282
423	EL037	-0.137	0.026	0.163	1.100	1.126	0.0282
424	EL002	-0.137	0.025	0.162	1.100	1.125	0.0282
425	EL001	-0.137	0.025	0.162	1.100	1.125	0.0282
426	P0887	-0.147	0.331	0.478	55.000	55.331	0.4158
427	EL039	-0.150	1.896	2.047	33.000	34.896	0.2919
428	EL040	-0.150	1.896	2.047	33.000	34.896	0.2919
429	EL038	-0.150	1.896	2.047	1.100	2.996	0.0751
430	P0609	-0.175	0.412	0.586	1.100	1.512	0.0126
431	EL145	-0.182	1.704	1.886	33.000	34.704	0.2903
432	EL032	-0.182	1.704	1.886	33.000	34.704	0.2903
433	LV012	-0.182	1.704	1.886	1.100	2.804	0.0703
434	P0081	-0.317	0.003	0.321	5.500	5.503	0.1379

Table F.2. (continued)

Seq	FNEM Arc LIC Code	FUA - Base (Megatons)	FUA Case Coal Volume (Megatons)	Base Case Coal Volume (Megatons)	Pre-Load Volume (Megatons)	FUA Case Total Volume (Megatons)	FUA Case Volume/ Capacity
435	P0079	-0.327	0.003	0.330	5.500	5.503	0.1379
436	BX033	-0.367	4.599	4.966	5.500	10.099	0.0845
437	BX030	-0.367	4.599	4.966	22.000	26.599	0.2225
438	P0005	-0.368	0.085	0.453	5.500	5.585	0.1399
439	P0008	-0.368	0.085	0.453	5.500	5.585	0.1399
440	P0005	-0.368	0.085	0.453	5.500	5.585	0.1399
441	BM061	-0.368	0.085	0.453	33.000	33.085	0.2486
442	BM057	-0.368	0.085	0.453	33.000	33.085	0.2486
443	P0019	-0.368	0.085	0.453	5.500	5.585	0.1399
444	BM058	-0.368	0.085	0.453	33.000	33.085	0.7487
445	BM035	-0.368	0.085	0.453	5.500	5.585	0.0467
446	BM084	-0.368	0.085	0.453	5.500	5.585	0.1399
447	P0005	-0.368	0.085	0.453	5.500	5.585	0.1399
448	P0019	-0.368	0.085	0.453	5.500	5.585	0.1399
449	P0591	-0.374	0.104	0.478	33.000	33.104	0.2488
450	P0890	-0.374	0.104	0.478	33.000	33.104	0.2488
451	P0889	-0.374	0.104	0.478	33.000	33.104	0.2488
452	P0023	-0.374	0.085	0.459	33.000	33.085	0.2486
453	P0023	-0.374	0.085	0.459	33.000	33.085	0.2486
454	P0022	-0.374	0.085	0.459	33.000	33.085	0.7487
455	P0022	-0.374	0.085	0.459	33.000	33.085	0.2486
456	P0768	-0.493	3.869	4.362	22.000	25.869	0.6482
457	P0058	-0.530	3.804	4.334	22.000	25.804	0.6466
458	P0058	-0.530	3.804	4.334	22.000	25.804	0.6466
459	P0767	-0.530	3.804	4.334	22.000	25.804	0.6466
460	P0067	-0.530	3.885	4.415	11.000	14.835	0.3730
461	P0617	-0.597	1.292	1.888	33.000	34.292	0.8593
462	P0618	-0.598	1.521	2.120	33.000	34.521	0.8650
463	P0827	-0.598	1.521	2.120	33.000	34.521	0.8650
464	P0080	-0.644	0.006	0.650	5.500	5.506	0.1380
465	P0078	-0.644	0.006	0.650	1.100	1.106	0.0277
466	P0779	-0.871	10.139	11.011	33.000	43.139	1.0810
467	P0642	-0.873	0.140	1.013	1.100	1.240	0.0311
468	BX035	-1.343	3.624	4.966	55.000	58.624	0.4406
469	P0195	-1.357	0.199	1.556	1.100	1.299	0.0325
470	P0221	-1.357	0.199	1.556	5.500	5.699	0.1428
471	P0223	-1.357	0.199	1.556	33.000	33.199	0.2495
472	P0228	-1.357	0.199	1.556	33.000	33.199	0.2495
473	P0693	-1.490	0.313	1.803	1.100	1.413	0.0354
474	P0693	-1.490	0.313	1.803	1.100	1.413	0.0354
475	P0116	-1.504	0.0	1.504	11.000	11.000	0.2756
476	P0110	-1.504	0.0	1.504	11.000	11.000	0.2756
477	P0117	-1.504	0.0	1.504	11.000	11.000	0.2489
478	P0140	-1.504	0.0	1.504	11.000	11.000	0.2756
479	P0109	-1.504	0.0	1.504	55.000	55.000	0.4133
480	BX034	-1.598	3.369	4.966	55.000	58.369	0.4386
481	RDG43	-1.836	0.140	1.976	33.000	33.140	0.2772
482	RDG42	-1.976	0.0	1.976	33.000	33.000	0.2760
483	RDG42	-1.976	0.0	1.976	33.000	33.000	0.2760
484	P0194	-2.303	2.986	5.289	55.000	57.986	0.4358
485	P0759	-2.326	0.586	2.912	55.000	55.586	0.4177
486	P0175	-2.326	0.586	2.912	1.100	1.686	0.0422
487	P0755	-2.326	0.586	2.912	55.000	55.586	0.4177
488	P0641	-2.326	0.586	2.912	55.000	55.586	0.4649
489	P0640	-2.326	0.586	2.912	33.000	33.586	0.1526
490	WM019	-2.479	3.887	6.366	1.100	4.987	0.1250
491	BX059	-2.479	3.887	6.366	33.000	36.887	0.9243
492	BX189	-2.479	3.887	6.366	1.100	4.987	0.1250
493	WM018	-2.479	3.887	6.366	1.100	4.987	0.1250
494	P0174	-2.756	0.123	2.879	22.000	22.123	0.5544
495	P0182	-2.756	0.123	2.879	22.000	22.123	0.5544
496	P0183	-2.976	3.561	6.537	55.000	58.561	0.4401
497	WM026	-3.153	1.777	4.930	11.000	12.777	0.1069
498	WM040	-3.153	1.777	4.930	1.100	2.877	0.0241
499	WM026	-3.407	1.777	5.184	11.000	12.777	0.1069
500	P0181	-3.489	3.233	6.723	55.000	58.233	0.4376

Table F.2. (concluded)

Seq	FNEM Arc LIC Code	FUA - Base (Megatons)	FUA Case Coal Volume (Megatons)	Base Case Coal Volume (Megatons)	Pre-Load Volume (Megatons)	FUA Case Total Volume (Megatons)	FUA Case Volume/ Capacity
501	P0173	-4.571	0.285	4.856	22.000	22.285	0.5584
502	P0169	-4.604	0.252	4.856	22.000	22.252	0.5576
503	P0224	-4.604	0.252	4.856	22.000	22.252	0.5576
504	P0171	-4.604	0.252	4.856	22.000	22.252	0.5576
505	CI002	-5.794	0.418	6.213	1.100	1.518	0.0380
506	P0113	-6.243	5.066	11.308	33.000	38.066	0.3184
507	P0113	-6.243	5.066	11.308	33.000	38.066	0.3184
508	P0179	-9.379	3.880	13.259	33.000	36.880	0.9241
509	P0189	-9.401	4.444	13.845	33.000	37.444	0.9383
510	P0634	-9.401	4.444	13.845	33.000	37.444	0.1702
511	P0188	-9.401	4.444	13.845	33.000	37.444	0.9383

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